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PARKScience

Integrating Research and Resource Management in the National Parks

National Park Service
U.S. Department of the Interior

Natural Resource Program Center
Office of Education and Outreach

SPECIAL ISSUE: SOUNDSCAPES RESEARCH AND MANAGEMENT

Understanding, protecting, and enjoying the acoustic environment of our national parks

- Measuring and monitoring park soundscapes
- Overflights management
- Profile: Acoustic Scientist Kurt Fristrup
- Consequences of noise to wildlife
- A quiet zone at Muir Woods
- Planning for soundscapes protection

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From the Guest Editors

From landscapes to soundscapes: Introduction to the special issue

By Peter Newman, Robert Manning, and Karen Treviño

A GROWING BODY OF RESEARCH HAS DOCUMENTED THE potential impacts of outdoor recreation and other activities in national parks and related areas (Hammitt and Cole 1998; Leung and Marion 2001). These impacts apply to multiple components of the landscape, including soil, vegetation, water, and wildlife. For example, visitors to parks can trample fragile vegetation, compact and erode soils, pollute water, and disturb wildlife. Moreover, there are often aesthetic implications of these impacts that can degrade the quality of the visitor experience (Manning et al. 2004). Research and management attention has logically extended from conventional landscapes to "soundscapes," or the acoustic environment, and includes consideration of aural impacts of human-caused noise.

Impacts of noise are increasingly pervasive

Excessive anthropogenic noise is becoming increasingly pervasive in society (Goines and Hagler 2007). Noise pollution can affect the physical and mental well-being of people through psychological annoyance, interference with speech, interruption of sleep, disruption of cognitive processes, temporary or permanent hearing disorders, and negative impacts on the cardiovascular and endocrine systems (Gramann 1999; Goines and Hagler 2007). Anthropogenic noise exposure can also significantly detract from the experience of visiting a national park. For example, significant decreases in scenic evaluations have been reported in association with the presence of anthropogenic sounds (Benfield et al. 2009, 2010).

Research has also begun to explore the restorative effects of natural environments, including the sounds of nature (Anderson et al. 1993; Tarrant et al. 1995). For example, people who have been exposed to cognitive fatigue reported higher positive emotional states and performed better on mental tasks after walking in a park, and these restorative effects were higher than for other treatments, such as walking in an urban area, reading, and listening to music (Hartig et al. 2003). Increased noise levels can also reduce the distance and area over which wildlife can detect changes in sounds. Research now indicates that human noise intrusions can produce substantial changes in wildlife behavior, breeding, and species success (Rabin et al. 2006).

Evolution of soundscapes as a management concern

With greater knowledge and understanding of the important role the acoustic environment plays in overall ecosystem health and visitor enjoyment as well as the potential impacts of anthropogenic noise, protection of the acoustic environment has received growing attention by managers and policy makers. In 1972, the Noise Control Act required that the federal government establish and enforce noise controls in work and other places, including national parks. Subsequent legislation to limit air tours and enforce minimum flight altitudes (to limit noise) was enacted for national parks such as Grand Canyon and Hawai'i Volcanoes. Legislation from the 108th Congress also limited snowmobile use at Yellowstone and Grand Teton national parks, and this has led to improved technology designed to reduce noise caused by snowmobiles, aircraft, and other forms of mechanized travel in national parks and related areas (Sheikh and Uhl 2004).

In 1987, the National Parks Overflights Act was passed by Congress and required assessment of noise impacts of overflights in national parks. In response, Grand Canyon National Park is developing an air tour management plan to ensure public safety and substantially restore natural quiet. In its 2003 *Federal Register* notice, the park defined substantial restoration of natural quiet as 50% or more of the park's airspace being free of aircraft noise for at least 75% of the day. Additionally, it specified that minimum flight altitudes must be observed and defined routes must be followed by air tour operators (Schwer et al. 2000).

Though the topic of noise was first addressed in the 1978 edition of *NPS Management Policies* (and later updated in 1988), the 2001 policies revision devoted an entire section to the protection of the acoustic environment as a resource just like air, water, and wildlife (National Park Service [NPS] 2001, section 4.9). Chapter 8 on "Visitor Use" also describes the importance of the acoustic environment to visitor enjoyment and states that recreation, including motorized recreation, cannot intrude on the opportunity to hear the sounds of nature in units of the National Park System or interfere with park interpretive talks. In 2000, Director's Order 47 (NPS 2000) was promulgated as a precursor to the pending management policies and further "requires, to the fullest extent practicable, the protection, maintenance, or restoration of the natural soundscape resource in a condition unimpaired by inappropriate or excessive noise sources." The order specifies how parks should monitor and plan to protect park soundscapes. The current version of *NPS Management Policies* (NPS 2006, section 5.3.1.7) added yet another section establishing the concept of "cultural soundscapes" for NPS protection.

CONTINUED ON PAGE 4

MASTHEAD CONTINUED

Park Science is a research and resource management bulletin of the U.S. National Park Service. It reports the implications of recent and ongoing natural and social science and related cultural research for park planning, management, and policy. Seasonal issues are published in spring and fall, with a thematic issue that explores a topic in depth published annually in summer or winter. It serves a broad audience of national park and protected area managers and scientists and provides public outreach. It is funded by the Associate Director for Natural Resource Stewardship and Science through the Natural Resource Preservation Program.

Articles are field-oriented accounts of applied research and resource management topics that are presented in nontechnical language. They translate scientific findings into usable knowledge for park planning and the development of sound management practices for natural resources and visitor enjoyment. The editor and board review content for clarity, completeness, usefulness, scientific and technical soundness, and relevance to NPS policy.

Article inquiries, submissions, and comments should be directed to the editor by e-mail; hard-copy materials should be forwarded to the editorial office. Letters addressing scientific or factual content are welcome and may be edited for length, clarity, and tone.

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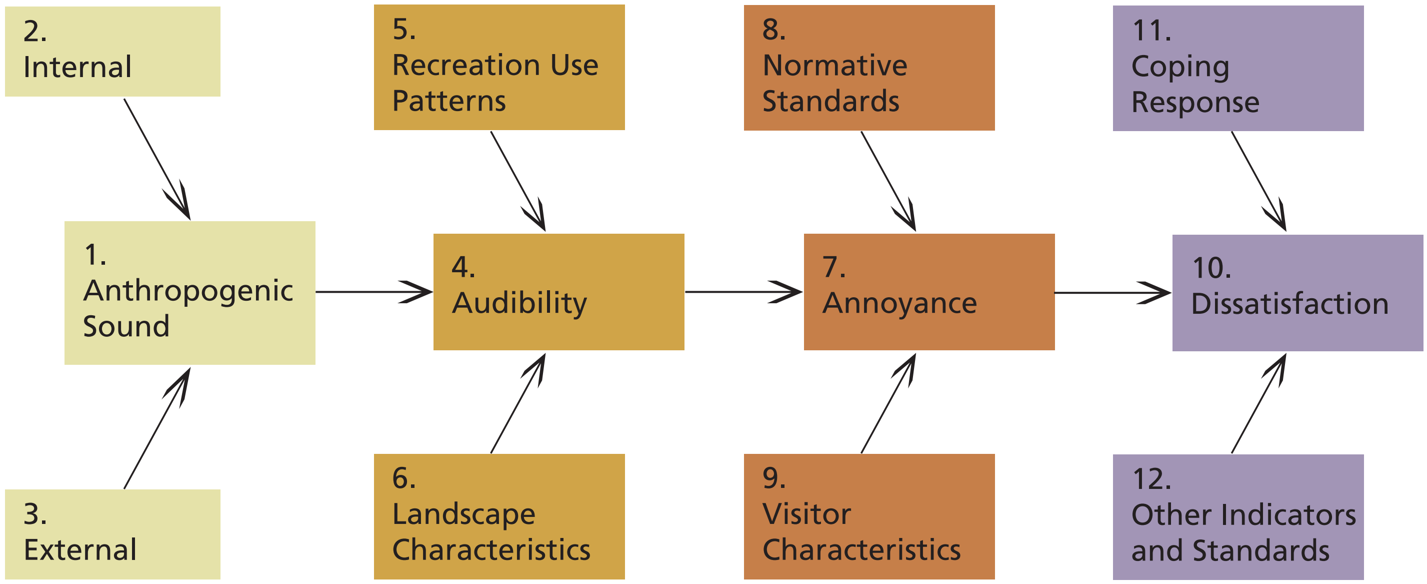

Figure 1. This model of soundscapes is conceptual and evolving, but provides a way to begin to organize and integrate multiple themes of research taking place in park units across the country. This systems approach allows park managers and researchers to explore the complex web of soundscapes and their intricate relationships with visitors, wildlife, and society that make up our National Park System.

Understanding soundscapes

Since 2003, the NPS Natural Sounds Program has partnered with researchers and acoustic science practitioners to better understand the challenges and benefits of protecting soundscapes. These partners have formed the core of a working group made up of university researchers and students, consultants, and NPS planners and managers to study the relationships among sound/noise, society, and ecosystems. In spring 2006 and fall 2007, workshops were held in Fort Collins, Colorado, cosponsored by the National Park Service and Colorado State University, providing a forum for planners, managers, and researchers to collaborate in organizing an approach to protecting soundscapes in national parks. One of the action items arising from these workshops was to prepare a special issue of *Park Science* addressing understanding and management of soundscapes in the national parks.

The workshops have developed an evolving conceptual model of soundscapes in parks that is related to similar models of human-caused impacts to parks and protected areas (Manning 1999). The model in figure 1 suggests that anthropogenic sounds (box 1) can emanate from both inside (e.g., park visitors, park administration, and services; box 2) and outside (e.g., aircraft; box 3) parks. The audibility of anthropogenic sounds (box 4) can be affected by recreation use patterns (e.g., recreation activities, behavior; box 5) and landscape features (e.g., topography, vegetation; box 6). Audible human-caused sounds can lead to annoyance (box 7), but this relationship is mediated by normative standards of visitors (societal judgments about acceptable conditions in parks; box 8) and related visitor characteristics (e.g., visitor motivations; box 9). This is the point at which the objective measure of sound becomes the more subjective notion of noise. When anthropogenic sounds are judged to be annoying (or otherwise undesirable), they can lead to dissatisfaction (box 10) with the quality of the park experience. But this can be mediated by a variety of cognitive and behavioral coping responses by visitors (box 11). For example, some visitors might be displaced from the park because it is too noisy, so they are no longer present to register their dissatisfaction. Moreover, soundscape-related issues are only one of potentially many indicators that might affect the quality of the visitor experience (box 12), and soundscape-related indicators may be more or less important depending on the context of the park. Though this model was constructed primarily from the standpoint of visitor impacts of human-caused noise, it might also be useful in the context of wildlife-related concerns. For example, stress might be substituted for annoyance, and impacts on feeding, reproductive, and migratory processes might be substituted for dissatisfaction.

Special issue

The articles in this special issue of *Park Science* address multiple components of this conceptual model. For example, Fristrup et al. (page 32) illustrate the science of measuring and monitoring anthropogenic sounds in national parks, including a variety of metrics associated with audibility. Manning et al. (page 54) describe research to identify normative standards for visitor-caused noise at Muir Woods National Monument and the efficacy of a series of experimental educational programs designed to influence visitor behavior and reduce visitor-caused noise. Park et al. (page 59) use a computer-based simulation model of road corridor noise at Rocky Mountain National Park to demonstrate the effects of landscape characteristics on the audibility of noise. Barber et al. (page 26) examine how human-caused noise can cause stress in wildlife, affecting reproductive success and predator-prey relationships. Such stress can lead to coping behaviors, but some species may not be able to adjust to increased levels of noise. Bell et al. (page 65) focus on the noise caused by aircraft overflights and explain the way in which the source of such noise can influence annoyance, normative standards for the maximum acceptable levels of noise, and visitor attitudes toward alternative management actions. McCusker and Cahill (page 37) describe the ways in which the National Park Service is addressing soundscape-related issues in park planning and management. Finally, this issue includes six "case studies" that demonstrate how park staff are managing and mitigating issues related to noise in national parks across the country (pages 42–53).

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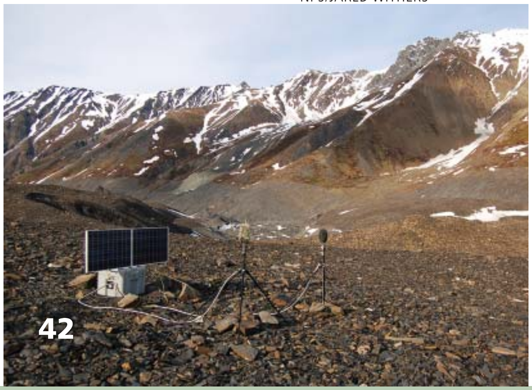

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ON THE COVER

A lone hiker explores the wilderness shore of Shi Shi beach at Olympic National Park, Washington. The experience is characterized by solitude to be sure, but not by silence. Rather, a rich suite of natural sounds envelops the hiker: waves breaking on the shore, wind in the trees, birds calling, deer munching grass, and even gently shifting grains of wind-blown sand. Protecting the sounds of nature is an increasingly important priority of national park managers. This photograph by Pablo McLoud was a winning entrant in the recent NPS-Olympus Photo Contest—2009.

NPS/PABLO MCLOUD

NPS/LOU SIAN

NPS PHOTO

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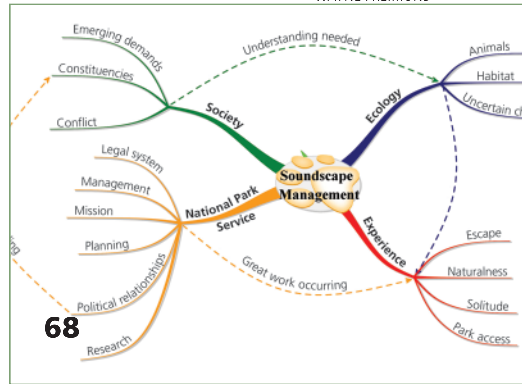

UPCOMING ISSUES

Spring 2010
Seasonal issue. Month-of-May release. Still accepting manuscripts for various departments and features through 12 February 2010.

Fall 2010
Seasonal issue. October release. Accepting contributions until 15 May 2010.

Winter 2010–2011
January 2011 release. Topical issue: Climate change research and management applications. Contributor's deadlines: 7 May (round 1) and 8 October (round 2).

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CASE STUDIES (CONT'D)

RESEARCH REPORTS

COMMENTARY ON THE SPECIAL ISSUE

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Correction

Mistaken identity

IN OUR LAST ISSUE (volume 26, number 2, page 78, figure 2) the map depicting parks and Inventory and Monitoring Program networks collaborating in the eastern forest vegetation monitoring initiative contained an error. We inadvertently labeled Shenandoah National Park as Great Smoky Mountains National Park and vice versa. We know the difference and apologize for the mistake. The Web site and PDF editions of the article have been corrected.

At Your Service

The collaborative nature of soundscapes research and management

By Lelaina Marin, Peter Newman, and Jeff Selleck


NPS PHOTO

Staff of the Natural Sounds Program. Top row: Chad Moore (Night Skies Program), Randy Stanley, Frank Turina, Lelaina Marin, Kurt Fristrup, Dave Stack. Bottom row: Karen Treviño, Ericka Pilcher, Emma Lynch, Charlotte Formichella, Damon Joyce, Vicki McCusker.

THE NATURAL SOUNDS PROGRAM Office, located in Fort Collins, Colorado, is part of the National Park Service's (NPS) Natural Resource Stewardship and Science Division. The program, which resides within the Natural Resource Program Center's Air Resources Division, was established in 2000 to help parks manage the acoustic environment in a way that protects park resources while providing for educational and inspirational visitor experiences. The Natural Sounds Program addresses sound-related matters raised by Congress, NPS management policies, and NPS director's orders. The general mission of the program is to protect, maintain, and restore acoustical environments throughout the National Park System by working in partnership with parks and others to increase scientific understanding and public appreciation of the value of soundscapes.

The program provides technical services to parks in the form of recreational planning assistance, acoustic monitoring, data collection and analysis, describing acoustic conditions, a military liaison, outreach and education, and research projects in areas of acoustics and social science. Program planners assist parks in the development of air tour management plans (working jointly with the Federal Aviation Administration), soundscape management plans, general management plans, wilderness plans, transportation plans, and visitor use plans. Planners also help parks plan for and manage specific noise source concerns. Acoustic specialists and technicians on staff help with acoustic monitoring, data analysis, instrument development, wildlife acoustics, and perceptual acoustics. The program's military liaison works with parks to mitigate impacts from military overflights. Parks can report military overflight concerns to the program liaison, who will contact the military to try to rectify the issue. Outreach and education efforts include development of outreach materials, guidance for interpretive programs, and Web site design. In addition, the Natural Sounds Program works in cooperation with various universities (e.g., Colorado State University, University of Vermont, Virginia Polytechnic Institute, University of Montana, and Southern Utah University) to complete both wildlife and social science research focusing on the acoustic environment.

Colorado State University (CSU) and the NPS Natural Sounds Program have a special relationship based on their cooperative research agreement and proximal location to each other in Fort Collins. This partnership has helped shape a research agenda and bring it to the forefront in addressing park management issues related to wildlife, social psychology, and visitor management. Faculty from the Warner College of Natural Resources and the Department of Psychology at CSU have written several peer-reviewed journal articles and produced master's students who have gone on to work for or in partnership with the National Park Service (table 1, next page). The vibrance of this partnership is evident in the number and variety of staff and faculty with the National Park Service, Colorado State University, and other universities responsible for the content of this special edition of *Park Science* (table 1, next page).

If you are interested in receiving assistance from the Natural Sounds Program please submit a technical assistance request (TAR) through the annual technical assistance call (contact your region for deadlines). Projects can also be submitted throughout the year by using http://nrpcstar.

Table 1. Contributors to the *Park Science* issue on soundscapes management

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*For a complete staff list of the Natural Sounds Program visit http://www.nature.nps.gov/naturalsounds/organization/.

PS

Profile

A conversation with Acoustic Scientist Kurt Fristrup

By the editor and associate editor

Editor's Note: This interview grew out of our interest to explore the science of soundscapes, and immediately Kurt Fristrup was suggested as our person. Articulate and energetic, Fristrup is a great scientist, eager to broaden his understanding and incorporate interdisciplinary applications of acoustics science. His vision, high motivation, and training are helping to advance our knowledge of park soundscapes in leaps and bounds.

Park Science: **Acoustical monitoring is a far step from biomedical engineering, the field in which you began your career. Which experiences led you to the National Park Service and the Natural Sounds Program?**

Kurt Fristrup: My family spent many wonderful vacations in national parks, and I have always been interested in applications of physics and engineering in biology. When I became aware that my interests could apply in environmental science, my focus shifted from biomedical research to ecology and evolutionary biology, and I got my PhD in these disciplines at Harvard. Although acoustics played no role in my graduate work, it was central to my subsequent research at Woods Hole Oceanographic Institution and the Cornell Laboratory of Ornithology. While at Cornell, I provided technical assistance to the Natural Sounds Program regarding acoustical monitoring and analysis. The program contacted me when a position opened that I could compete for, and I was thrilled to be able to unite my interests in national parks and research.

"Soundscape" is a new concept to many people. What is it? Which natural features and processes are part of a soundscape? Which cultural features and processes are part of a soundscape?

KF: "Soundscape" refers to the entire environment as perceived through hearing. This includes perception of the spatial arrangement of sounds as well as the scheduling and structure of each sound. "Soundscape" is sometimes used to refer to the physical environment that supports sound propagation, though I prefer to call this the acoustical environment.

Our ability to perceive the soundscape relies upon the presence of sounds, our hearing capacity, and the way we categorize and identify incoming sounds. The integrity and authenticity of a soundscape depend upon the presence of the appropriate sounds and a quiet background in which to perceive them. The richness of what we perceive depends upon attentive listening and

Many visitors may be unaware that attentive listening can enrich their experience of park resources.

knowledge of what to listen for.

Which sounds are threatened? Which sounds do we need to preserve for future generations?

KF: The most threatened resource is a noise-free background in which to hear natural sounds. Very distant noise sources can damage the setting of quiet sites, interfering with the capacity of wildlife and park visitors to perceive subtle sounds. The National Park Service has strong legislative and policy mandates to conserve the sounds of wildlife along with healthy populations.

What research is needed to help understand and preserve soundscapes in national parks?

KF: Although there are numerous studies documenting the responses of visitors and wildlife to loud noise events, the effects of chronic exposure to less obvious noise sources are not as well understood. The effects of noise on backcountry visitors and on visitor perceptions of wilderness are also important research topics.

How are sounds important for overall ecosystem health?

KF: Hearing is the universal alerting sense for animals. Sounds alert animals to events all around them, even when the animals are occupied with foraging, parental care, or even sleeping. When noise compromises this awareness, animals may have limited options to compensate through increased visual scanning. Many predators rely heavily on listening to find prey, and many of their targets listen intently to avoid being eaten. In addition, many animals rely heavily on acoustical communication to defend territories, attract mates, and communicate with their young.

How is sound different for wildlife and humans?

KF: Many park visitors do not listen as intently as a wild animal would. Noisy urban environments can train us to ignore sounds, and many visitors may be unaware that attentive listening can enrich their experience of park resources. Some animals have much more sensitive hearing than humans—owls are a good example—but humans are rarely able to take full advantage of our hearing because noise levels in our communities mask our capacity to hear quiet or subtle sounds. Increasingly, noise is masking the ability of animals to take full advantage of their hearing capabilities.

Is there a catalog or library of unique sounds throughout the National Park System?

KF: We have some examples of natural sounds on our Web site (http://www.nature.nps.gov/naturalsounds/). We have tens of thousands of hours of digital audio files in our archive, which includes a selection of unusual or illustrative recordings.

How have park managers applied your data? Would you give specific examples?

KF: Acoustical monitoring data are informing the development of many NPS management plans: off-road vehicles at Cape Hatteras, winter use at Yellowstone, and air tours at Grand Canyon and many other national park units.

Research and acoustical monitoring at Muir Woods revealed that visitors responded very favorably to signs asking them to make special efforts to be quiet. The success of this program encouraged Muir Woods to permanently designate a quiet zone in Cathedral Grove.

The Natural Sounds Program is relatively new. What lessons have you learned helping to develop a fledgling program within an established organization like the Natural Resource Program Center and the National Park Service?

KF: Effective resource conservation always involves partnerships. Innovative acoustical monitoring analysis has been one part of our program's effort. Another major effort has been to develop collaborations with other divisions in the Natural Resource Program Center, and to demonstrate the relevance of our work for the regions and park units. Interpretation and outreach have proven critical to enhancing our value within the service, just as they are critical to enhance the experience of park visitors.

In what direction(s) would you take the Natural Sounds Program?

KF: The planning staff is working to establish consistent management practices for all acoustical resources. The science and engineering staff is working to extend our efforts to provide continuous, real-time monitoring of park acoustical conditions, information that could enliven interpretive programs and support law enforcement. We need to extend our capabilities to cover underwater sounds and vibration. Noise and vibration can present significant problems for cultural and historic sites. The grand challenge is to devise innovative approaches for providing access to parks that enhance visitor experience and minimize noise intrusions.

In order for the Natural Sounds Program to be successful, how do park managers and visitors need to change how they think about sounds/noise? What are the opportunities for education and outreach?

KF: We can all be better listeners. Parks provide outstanding opportunities to resuscitate visitor hearing, to help them enjoy an immersive experience of park soundscapes. Educational materials can help visitors identify unusual or ecologically important sounds, and train their ears to guide them to compelling views of wildlife behavior.

What significant findings has the program revealed? How are these helping to shape Service-wide practices and policies?

KF: Most backcountry areas in national parks experience substantial numbers of noise events per day. Noise is typically audible 20–30% of the day, and some remote areas have hours in which noise is audible almost 70% of the time. This emerging picture of pervasive noise exposure poses a fundamental challenge to the management of wilderness in national parks and other federal lands.

Take us through a monitoring scenario. Which methods do you apply? What equipment do you use? What are some of the logistics?

KF: The first step is to work with the park unit to discuss acoustical issues that pertain to park management objectives, and identify monitoring locations that will provide relevant data. Monitoring locations are often identified using Geographic Information Systems analyses. The equipment must often be packed into backcountry locations, so it has been designed to minimize size and weight. If the park envisions a need for modeling of potential scenarios or evaluation of monitoring data in relation to specific noise sources, then each monitoring station will have a sound level meter, a digital audio recorder, and a weather station. Inventories of natural sounds and noise sources can be accomplished without the sound level meter and weather station, resulting in a smaller and much less expensive package. Four years ago the monitoring stations weighed more than 250 pounds and consumed 14 watts of power. Today they weigh less than 50 pounds (with batteries) and consume about 2 watts.

All equipment is housed in weather- and bear-resistant containers, and all cabling is sheathed to inhibit chewing. Field technicians must survey the general vicinity of the chosen location to find a site that has representative vegetation, soil, and topography, and is not especially exposed to wind. Wind generates pseudonoise when it flows over a microphone wind shield, which inhibits monitoring of the wind sounds that are part of the natural environment. The microphone and anemometer are set up on tripods, each of which is secured with guy wires and stakes to prevent tipping. Solar panels are often used at exposed sites, to extend battery lifetime, but our monitoring systems can run for more than a month with batteries of reasonable size and weight. The acoustical and weather instruments must be set up with proper monitoring parameters. When everything is connected and ready, the field technicians start up the instruments and secure the housings.

Noise is masking the ability of animals to take full advantage of their hearing capabilities.

What are the standards for acoustical monitoring? How would you improve these?

KF: Historically, acoustical monitoring in parks focused on ANSI Type 1 sound level measurements. We have improved on this practice by adding continuous audio recording. The combined data enable us to identify and archive the natural and cultural sounds of park settings, as well as the sources of noise. In the future, we expect to utilize multichannel audio recording to preserve the spatial structure of the soundscape, as well as the identities of the sounds and the background sound level. The multichannel systems will allow us to localize sound sources, enabling us to map wildlife activity and track noise sources.

What is the most exciting natural sound you've experienced in the field?

KF: Equipment that I helped develop and deploy recorded sounds of ivory-billed woodpeckers, and I may have heard the bird in Congaree National Park. This species was previously thought to have gone extinct. This project combined the thrill of discovery with a profound opportunity to revitalize conservation efforts for eastern floodplain forests.

Information Crossfile

Synopses of selected publications relevant to natural resource management

ARTICLE

Hearing perception

IN ACCORDANCE WITH THE NATIONAL PARK SERVICE Organic Act and Chapter 8 of NPS *Management Policies 2006*, the fundamental purpose of all national park units includes providing for the enjoyment of park resources such as the soundscape. Hearing is fundamental to visitor perception of the soundscape and cannot easily be divorced from condition assessment of that resource. Most current soundscape metrics have their basis in human hearing, ranging from audibility functions to weightings that approximate hearing sensitivity. Therefore, it is helpful for park managers to have a fundamental understanding of the hearing process.

Hearing is a complex process that involves various aspects of physics, physiology, and neural processing (including psychology). Physics comes into play when incoming sound waves are modified, that is, filtered, by the shape and position of the listener's head, ears, and shoulders. This spatial filtering presents cues that neural processing in the brain can utilize to detect the approximate location, distance, and movement of sound sources. The physiology of the entire ear system affects how well sounds can be heard and at what frequencies they may be masked (rendered inaudible by another sound).

Human auditory perception is a multimodal process (Bulkin and Groh 2009). Sound carries information about the source, and this information can be judged in various ways. Response judgments may include interpretations of meaning (potential danger, speech communication), pleasantness (soothing ocean wave sounds), and undesirability (annoying noise), for example. Perception of sound sources is not limited to the sense of hearing. Visual-auditory interactions play a prominent role in perception. The image intrinsic to sound sources affects the evaluation of sounds. The converse is also true: A sound can affect the perceived quality of an image or a visual landscape (Carles et al. 1999). For example, studies show that the pleasantness and beauty of outdoor settings are impacted by multiple interconnected senses. For an outdoor location to be judged as "tranquil," a certain visual and sound quality level is usually required.

It is well-known that a listener's expectation and experience play significant roles in the perception of sound. Auditory attention elasticity—the ability to switch attention between environmental sounds—depends on the context and mind state of the listener, the individual's activity, and the loudness of environments that precede the moment of auditory perception (De Coensel and Botteldooren 2008). For example, if a listener is habituated to a noisy airplane, snowmobile, or automobile ride immediately preceding a tranquil walk in the woods, some amount of time may need to pass before the listener is able to fully appreciate and focus on a combination of peaceful sounds in the quieter, natural setting.

If a listener is habituated to a noisy airplane, snowmobile, or automobile ride immediately preceding a tranquil walk in the woods, some amount of time may need to pass before the listener is able to fully appreciate and focus on a combination of peaceful sounds in the quieter, natural setting.

The masking of sounds by noise, or conversely, the audibility of sounds, is an important perceptual factor when communication is involved. However, because masking is mainly dependent on physiological aspects of hearing and there is a fairly abrupt transition region between audibility and inaudibility, it cannot fully describe human perceptual response. Auditory attention focusing has been proposed as another means for modeling soundscape perception (De Coensel and Botteldooren 2008). Auditory attention focusing comprises both top-down (directed) focusing, in which higher-level cognition guides attention toward expected sound sources, and bottom-up focusing, in which attention is triggered by the noticing of sound events.

Studies also indicate that natural sounds offer potential benefits for cognitive functioning and directed attention abilities. Unlike urban environments, with stimulation that dramatically captures attention, natural sounds modestly grab attention in a bottom-up fashion, allowing top-down directed attention abilities a chance to replenish (Berman et al. 2008). This provides further support for park management efforts to preserve the natural soundscape and the opportunity for visitors to experience those sounds.

References

Berman, M. G., J. Jonides, and S. Kaplan. 2008. The cognitive benefits of interacting with nature. Psychological Science 19:1207–1212.

Bulkin, D. A., and J. M. Groh. 2009. Seeing sounds: Visual and auditory interactions in the brain. Current Opinion in Neurobiology 16:415–419.

Carles, J. L., I. Lopez Barrio, and J. Vicente de Lucio. 1999. Sound influence on landscape values. Landscape and Urban Planning 43:191–200.

De Coensel, B., and D. Botteldooren. 2008. Modeling auditory attention focusing in multisource environments. Proceedings of Acoustics '08, Paris, 29 June–4 July 2008. La Société Française d'Acoustique, Paris, France. Accessed 5 August 2009 at http://intellagence.eu.com/acoustics2008/acoustics2008/cd1/data/articles/001999.pdf.

—G. (Randy) Stanley
Acoustic Specialist, Natural Sounds Program, National Park Service

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SUMMARIES

Australian campers weigh in on noise

INAPPROPRIATE, LOUD, OR EXCESSIVE NOISES in recreation areas can be a source of conflict among visitors, detract from the overall experience, and degrade park resources. Diana Beal's research in three Queensland national park (Australia) campgrounds is on campers' attitudes toward noise sources and potential regulatory efforts by the park. Rangers distributed surveys that asked campers to provide their perceptions of 10 different noises, including human-caused, natural, and technology-based events. For those sounds that irritated or annoyed visitors, they were asked to give their opinion on whether more passive or active regulation was needed by the park. Natural sounds, such as those of birds and insects, were rated as the most pleasant, while loud technology, such as radios and televisions, was deemed most annoying by the campers. Respondents rejected management regulation that would create stricter rules for behavior; however, they favored the idea of more patrols by park officials to enforce the rules. Beal recommends that managers consider zoning parts of the campgrounds to accommodate visitors who arrive after a "reasonable hour" to limit the number of noise intrusions from late arrivals.

Reference

Beal, D. 1994. Campers' attitudes to noise and regulation in Queensland national parks. Australian Parks and Recreation 30(4):38–40.

—Dave Stack
Park Ranger, Statue of Liberty National Monument, New York, and former acoustic technician and research associate, Colorado State University, Fort Collins, Colorado, working for the National Park Service under cooperative agreement. He can be reached at dave_stack@nps.gov.

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Preserving silence in national parks

GARRET KEIZER, WRITER FOR *SMITHSONIAN MAGAZINE*, traveled to the NPS Natural Resource Program offices in Fort Collins, Colorado, to learn more about the Natural Sounds Program and to take a peek at the lives and work of the staff there. When he walked through the door, "cases of sound equipment—cables, decibel meters, microphones—were laid out like a dorm room's worth of gear on the hallway carpet … members of the team were preparing for several days of intensive work out in the field." Established in 2000, the Natural Sounds Program works to protect, maintain, and restore acoustical environments throughout the National Park System. With 185,000 air tours flying over parks every year, much of this research informs management planning efforts mandated by the National Parks Air Tour Management Act of 2000. From a policy perspective, the program asks what noises are appropriate for park settings and at what levels. Program Director Karen Treviño explains that the National Park Service has made significant progress in combating noise, yet much remains to be done. Examples of those successes include a propane-fuel shuttle system in Zion National Park that has made the canyon quieter, the establishment of a quiet zone in Muir Woods National Monument that allows visitors to enjoy a moment of silence among the redwoods, and cooperation from military overflights in Sequoia–Kings Canyon National Parks to fly above 3,000 feet. These successes may seem like small victories, but they may provide monumental opportunities for park visitors and wildlife.

Reference

Keizer, G. 2008. Preserving silence in national parks: A battle against noise aims to save our natural soundscapes. Smithsonian Magazine. Accessed 1 December 2008 from http://www.smithsonianmag.com/science-nature/sounds-in-parks.html.

—Ericka Pilcher
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PODCAST

Yosemite voices

***YOSEMITE VOICES* IS AN AUDIO PODCAST SERIES** intended to provide insights into the natural and cultural history and management of Yosemite National Park. It also explores the lives and lifestyles of the people who live and work there. In Episode 1, entitled “Soundscapes,” Ranger Bob Roney interviews Kurt Fristrup, PhD, the senior acoustic specialist with the National Park Service’s Natural Sounds Program in Fort Collins, Colorado. He talks about the effect of noise on predator-prey relationships, animal communications, and human physiology. Fristrup reveals some of the findings about the acoustic health of Yosemite as well as interesting discoveries from recordings made in the wilderness. He explains that noise can impact the acoustic environment much as smog can impact the visual environment because it obscures the listening horizon for both visitors and wildlife. Working with staff of the Natural Sounds Program, Yosemite has conducted monitoring at 13 locations across the park. Each acoustic monitoring station was set up for a month and gave park staff baseline information about the park’s natural sounds and noise intrusions. The natural sounds detected include a sniffing black bear near the microphone, the dawn chorus of birds, and the thunder of waterfalls throughout the park. The principal noise source detected in Yosemite’s backcountry was from aircraft, with the average interval between noise events being three minutes. The good news is that between these noise events, Yosemite’s backcountry is full of exciting and intriguing natural sound events that connect visitors to the landscape. It is a powerful place that can take visitors back in time and provide an opportunity for respite, inspiration, and solitude. Ranger Roney encourages visitors to close their eyes to the landscape for just a moment, and open their ears to the soundscapes. By doing so, they may gain a whole new perspective on the environment around them.

Ranger Roney encourages visitors to close their eyes to the landscape for just a moment, and open their ears to the soundscapes. By doing so, they may gain a whole new perspective on the environment around them.

Reference

Roney, B., host. 2008. Soundscapes [Episode 1]. Yosemite Voices. Podcast retrieved from http://www.nps.gov/yose/photosmultimedia/yv1-soundscapes.htm (August 2008).

—Ericka Pilcher

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RADIO BROADCAST

National Public Radio broadcast summarizes acoustic monitoring project

Editor’s Note: The research summarized here is described in detail in a report by L. Park et al. on page 59.

DAN MEYERS, RADIO HOST OF KCFR’S *COLORADO MATTERS*, interviewed the National Park Service (NPS) Natural Sounds Program scientist Dr. Kurt Fristrup about acoustical research the program conducted in Rocky Mountain National Park. Over the summer of 2008, researchers conducted acoustic monitoring and recorded sounds in the park in order to determine whether transportation noise from roads disrupts visitor enjoyment of some of the park’s trails.

Monitoring acoustic resources requires specialized equipment that researchers can leave unattended in the backcountry for weeks at a time. In the case of the Rocky Mountain National Park research, a monitoring device was deployed in the park at a base station, and a researcher walked trails in the area collecting data with a mobile acoustical monitoring device. These data can be used to model the propagation of sound through the area.

Using this research as an example, the broadcast is a primer for understanding why and how the Natural Sounds Program collects acoustic data in parks. Results from this work will help park managers determine which areas of the park are most quiet, which management actions are needed to reduce inappropriate noise, as well as which sound sources are creating the most noise. This has the potential to benefit the visitor experience in the park as well as to create a healthier environment for park wildlife.

Reference

Meyers, D., host. 2008, October 14. Scientists study sound in Rocky Mountain National Park. Colorado Matters, KCFR News. http://www.kcfr.org/index.php?option=com_content&task=view&id=497.

—Dave Stack

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ANNOTATED BIBLIOGRAPHY

Editor's Note: The following annotated bibliography, prepared by Kurt Fristrup of the Natural Sounds Program, supplements references listed elsewhere in this issue and may be useful to park managers who are dealing with specific noise issues, as follows:

Overflight effects on birds

The responses of nesting red-tailed hawks (with nestlings) to helicopter overflights (30–45 m [33–49 yd] above ground level, 45–65 km/hr [28–40 mi/hr]) were measured. Nine out of twelve birds flushed at a site with no previous experience with helicopter overflights, versus one out of twelve at a site with a history of exposure. Habituation was inferred, and presumed to reduce the impacts of overflights.

Andersen D. E., O. J. Rongstad, and W. R. Mytton 1993. Response of nesting red-tailed hawks to helicopter overflights. Condor 91(2): 296–299.

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Breeding owls were exposed to helicopter flights and chain saw noise from the ground. The chain saw stimulus evoked more responses than the helicopter flights, despite lower sound levels. The authors suggest this may reflect different sensitivities to these stimuli. Owls showed an alerting response when helicopters were 403 m (441 yd) away (on average), but no response was observed when helicopters were more than 660 m (722 yd) distant. Alerting responses returned to normal levels 10–15 minutes after the trial. Trials that involved close approaches to the nest appeared to decrease food delivery rates. The authors assert that a 105 m (115 yd) protection zone should eliminate flush responses and food delivery rates.

Delaney, D. K., T. G. Grubb, P. Beier, L. L. Pater, and M. H. Reiser. 1999. Effects of helicopter noise on Mexican spotted owls. Journal of Wildlife Management 63(1): 60–76.

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For both of the above articles, note that flushing is a relatively coarse measure of response, and it may not be a probable or effective natural response to an aerial threat.

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Four species of ducks exhibited infrequent responses to aircraft overflights in a free-ranging setting. Percentage of time in resting behavior was inversely related to noise exposure, and was the behavioral state that was most susceptible to a response (9 of 14 observations). These findings suggest that aircraft disturbance did not diminish the quality of the study area habitat for waterfowl.

Conomy, J. T., J. A. Collazo, J. A. Dubovsky, and W. J. Fleming. 1998. Dabbling duck behavior and aircraft activity in coastal North Carolina. Journal of Wildlife Management 62(3):1127–1134.

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Captive black and wood ducks were exposed to aircraft overflights and noise from simulated overflights. Black ducks exhibited a rapid reduction in behavioral response upon repeated exposure; wood ducks exhibited a less consistent response, with two groups appearing to become sensitized (increased response with increased experience). Habituation is interpreted has having diminished the impact of overflights.

Conomy, J. T., J. A. Dubovsky, J. A. Collazo, and W. J. Fleming. 1998. Do black ducks and wood ducks habituate to aircraft disturbance? Journal of Wildlife Management 62(3):1135–1142.

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Harlequin ducks exhibited decreased courtship behavior for up to 1.5 hours after an overflight, and increased agonistic behavior for up to 2 hours. These were latent responses; the changes in behavior did not appear during or immediately after overflights. The authors note that effects on time-energy budgets may be more severe than might be inferred from short-term behavioral reactions to overflights. They note the probable connection between the latent behavioral responses and a physiological stress response. Peak sound levels for overflights were about 110 dB(A), against ambient backgrounds of 55 and 68 dB(A).

Goudie, R. I., and I. L. Jones. 2004. Dose-response relationships of harlequin duck behavior to noise from low-level military jet over-flights in central Labrador. Environmental Conservation 31(4):289–298.

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These proceedings have several articles of interest. Don Hunsaker's work on gnatcatchers and vireos on military bases in southern California documents decreased reproduction in relation to weekly A-weighted noise exposures. This trend was not statistically significant (measured as a linear regression of eggs laid or fledglings on weekly sound level) due to high levels of variation in the reproductive parameters (and possibly heteroscedasticity).

Effects of noise on wildlife. Conference proceedings, Happy Valley-Goose Bay, Labrador, 22–23 August 2000. Institute for Environmental Monitoring and Research. ISSN 1481-0336.

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Overflight effects on ungulates

Radio-tagged individuals were found to move significantly farther following a survey helicopter overflight than on control days.

Bleich, V. C., R. T. Bowyer, A. M. Pauli, M. C. Nicholson, and R. W. Anthes. 1994. Mountain sheep (*Ovis canadensis*) and helicopter surveys: Ramifications for the conservation of large mammals. Biological Conservation 70:1–7.

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The most important factor predicting mountain goat disturbance from helicopter flights was distance. Eighty-five percent of groups that were approached to within 500 m (547 yd) were disturbed, as opposed to 9% of groups that were not approached within 1,500 m (1,641 yd). Seven percent of the flights caused the group to split. One animal was injured while running from the helicopter.

Cote, S. D. 1996. Mountain goat responses to helicopter disturbance. Wildlife Society Bulletin 24:681–685.

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Probability of fleeing depended on a multiplicative effect of minimum distance to the aircraft trajectory and distance to rocky slopes. Sheep that were closer to rocky slopes were less likely to flee, and moved less distance when they did flee. Distances fled ranged from 15 m to 1.5 km (16 yd to 0.9 mi). Groups were much more likely to interrupt rest than to flee. Resting groups exhibited significant response probabilities at ranges up to 1.5 km (0.9 mi) in some scenarios, and took longer to end vigilance than animals that had been more active prior to the overflight (they did not resume rest within 10 minutes).

Frid, A. 2003. Dall's sheep responses to overflights by helicopter and fixed-wing aircraft. Biological Conservation 110:387–399.

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Disturbance responses were modest for an approach distance of 1 km (0.6 mi), and odds of disturbance increased by 25% for every decrease of 100 m (109 yd) in distance. The length of disturbance response was about 30 seconds, on average.

Goldstein, M. I., A. J. Poe, E. Cooper, D. Yonkey, B. A. Brown, and T. L. McDonald. 2005. Mountain goat response to helicopter overflights in Alaska. Wildlife Society Bulletin 33(2):688–699.

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This paper includes an anecdotal report of a golden eagle preying on a Dall sheep lamb that was separated from its parent by a helicopter overflight.

Nette, T., D. Burles, and M. Hoefs. 1984. Observations of golden eagle (*Aquila chrysaetos*) predation on Dall sheep lambs. Canadian Field Naturalist 98:252–254.

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Helicopters caused a notable reduction in foraging efficiency. Disturbance distances were approximately 250–450 m (274–492 yd).

Stockwell, C. A., and G. C. Bateman. 1991. Conflicts in national parks: A case study of helicopters and bighorn sheep time budgets at the Grand Canyon. Biological Conservation 56:317–328.

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Visitor noise effects

This study documented increased vigilance, decreased foraging rate, and movements away from people. Visitor noise was scored subjectively by the observers. Noise score was more important than the number of visitors in predicting bird response. Noise score was not correlated with the number of visitors. Education and supervision of visitors was suggested as being likely to be an effective mitigation.

Burger, J., and M. Gochfeld. 1998. Effects of ecotourists on bird behaviour at Loxahatchee National Wildlife Refuge, Florida. Environmental Conservation 25:13–21.

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Community noise

Community noise studies have relied heavily on A-weighted power spectra that are averaged over long intervals (an hour, a day, even a year). The authors note that these measurements typically explain less than half of the variation in responses to noise as measured in surveys. This laboratory study demonstrates that sounds with an identical power spectrum can evoke very different assessments of annoyance. Thus, the relative phases of different frequency components matter in these judgments, not just the amplitudes of these components. The authors also emphasize the importance of experience and the context in which the sound is presented. This finding supports the current NPS practice of obtaining continuous recordings as well as sound level measurements to characterize acoustical conditions in parks.

Fidell S., M. Sneddon, K. Pearsons, and R. Howe. 2002. Insufficiency of an environmental sound's power spectrum as a predictor of its annoyance. Noise Control Engineering Journal 50:12–18.

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Wind energy

This study documents substantial reduction in densities of grassland birds within 80 m of wind turbines (58.2–128.0 males/100 ha [23.6–51.9 males/100 ac]) relative to sites without wind turbines or sites more than 180 m from wind turbines (261.0–312.5 males/100 ha [105.6–126.5 males/100 ac]) in southwestern Minnesota.

Leddy, K. L., K. F. Higgins, and D. E. Naugle. 1999. Effects of wind turbines on upland nesting birds in conservation reserve program grasslands. The Willson Bulletin 111:100–104.

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Urban noise impacts

This review identifies the variety of changes in bird song that are plausibly related to urban noise, and discusses proximate and long-term processes of changes in animal communication that may result.

Particelli G. L., and J. L. Blickley. 2006. Avian communication in urban noise: Causes and consequences of vocal adjustment. The Auk 123(3):639–649.

■ ■ ■

This article emphasizes the temporal and spatial variations in noise exposure (in addition to level), as well as the effects of numerous vertical reflecting surfaces (reverberation).

Warren P. S., M. Katti, M. Ermann, and A. Brazel. 2006. Urban bioacoustics: It's not just noise. Animal Behaviour 71:491–502.

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Park visitor responses to noise

These studies documented responses of visitors to a park near an international airport. Visitors were more annoyed on day 2 than day 1 of the survey: equivalent annoyance required LAeq to be 10 dB(A) higher on day 1 for an equivalent response. The 50% "not acceptable" threshold was crossed at about 50 dB(A) on day 2 and 60 dB(A) on day 1. These tests were repeated with field recordings from day 1 in a subsequent laboratory test. Using LAE (or SEL, which does not divide integrated noise energy by the duration of exposure), the 50% "not acceptable" threshold was crossed at about 80 dB(A). Subsequent correspondence with the authors confirms that the 2004 result is equivalent to the 60 dB(A) finding of 50% "not acceptable" ratings for LAeq on day 1 of the 1999 field study (duration of exposure was approximately 100 seconds).

Aasvang, G. M., and B. Engdahl. 1999. Aircraft noise in recreational areas: A quasi-experimental field study on individual annoyance responses and dose-response relationships. Noise Control Engineering Journal 47(4):158–162.

Aasvang, G. M., and B. Engdahl 2004. Subjective responses to aircraft noise in an outdoor recreational setting: A combined field and laboratory study. Journal of Sound and Vibration 276(3–5):981–996.

■ ■ ■

Evaluations of visual settings and sounds were obtained in field and laboratory experiments. Wooded settings were strongly preferred over downtown street settings. There were strong interactions between scene and sound evaluations. Sounds in wooded settings exhibited a wider range, in terms of enhancing or detracting from the setting. Sounds and the interaction of sounds with site explained 41% of the variation in assessments of site quality. Natural sounds were most preferred. Sounds play a lesser role in determining site quality in urban settings than in wooded settings.

Anderson, L. M., B. E. Mulligan, L. S. Goodman, and H. Z. Regen. 1983. Effects of sounds on preferences for outdoor settings. Environment and Behavior 15(5):539–566.

■ ■ ■

The primary effect of aircraft overflights on visitors is noise. Direct questioning regarding noise is the most effective approach to measuring effects of overflights.

Booth, K. L. 1999. Monitoring the effects of aircraft overflights on recreationists in natural settings. Noise Control Engineering Journal 47(3):91–96.

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This paper established a high correlation across sites between awareness of noise and annoyance. Very high levels of annoyance were measured from aircraft noise at the Milford Track, which greatly exceeded noise levels then measured at Yosemite and Grand Canyon national parks. This paper notes visitor safety concerns associated with not being able to hear an approaching hazard.

Cessford, G. R. 1999. Recreational noise issues and examples for protected areas in New Zealand. Noise Control Engineering Journal 47(3):97–103.

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The prevalence of any level of noise-induced annoyance among visitors to several wilderness areas varied between 5% and 32%. Annoyance was more strongly related to noise exposure than the visibility of aircraft or their condensation trails.

Fidell, S., L. Silvati, R. Howe, K. S. Pearsons, B. Tabachnick, R. C. Knopf, J. Gramann, and T. Buchanan. 1996. Effects of aircraft overflights on wilderness recreationists. Journal of the Acoustical Society of America 100(5):2909–2918.

■ ■ ■

Graham, O. J. 1999. Measuring the effects of commercial jet boats on the Dart River on the experiences of recreationists in natural settings. Noise Control Engineering Journal 47(3):104.

Twenty-two percent of visitors reported being annoyed by jet boats, having noticed between four and seven boats. Visitors judged that double this number of boats would ruin their visit.

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There is no apparent relationship between the loudness of sounds and their ranking on an annoyance-pleasantness scale. The three most common annoying noise sources were rowdy people, music, and motorcycles. Mountaineers exhibited a broader range of annoyance-pleasantness ratings than campers, with much higher annoyance ratings for some sounds.

Kariel, H. G. 1990. Factors affecting responses to noise in outdoor recreational environments. The Canadian Geographer 34(2):142–149.

■ ■ ■

Visitor surveys at Grand Canyon, Hawai'i Volcanoes, and Haleakala National Parks were conducted in concert with measurements of noise doses. Annoyance and interference with appreciation of natural quiet and the sounds of nature were the visitor response measures. The dose-response relationship varied substantially across sites, with visitors at "short hike" sites being more sensitive than visitors at overlooks. Visitors expressed higher levels of interference with appreciation of natural quiet than annoyance, for a given noise dose. Audibility and aircraft noise Leq (average noise energy) were largely uncorrelated for all visitors, suggesting that these may represent independent dimensions of exposure.

Miller, N. P. 1999. The effects of aircraft overflights on visitors to U.S. National Parks. Noise Control Engineering Journal 47(3):112–117.

■ ■ ■

A concise review article whose findings could be applied to the effects of transportation noise adjacent to and within parks on park visitor experience.

Ouis, D. 2001. Annoyance from road traffic noise: A review. Journal of Environmental Psychology 21:101–120.

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A visitor survey at Padre Island National Seashore revealed which factors had the strongest potential to interfere with quality of experience. Seven of the top ten factors were related to noise, many of them directly ("loudness," "loud radios"). Fifty-seven percent of respondents indicated that the most appropriate volume level for radios could "be heard only by people within 10 feet."

Ruddell, E. J., and J. Gramann. 1994. Goal orientation, norms, and noise-induced conflict among recreation area users. Leisure Sciences 16(2):93–104.

■ ■ ■

Skiers were negatively affected by snowmobile encounters. Skiers who encountered snowmobiles rated noise impacts more severely than skiers who did not.

Vitterso, J., R. Chipeniuk, M. Skar, and O. I. Vistad. 2004. Recreational conflict is affective: The case of cross-country skiers and snowmobiles. Leisure Sciences 26(3):227–243.

■ ■ ■

Park noise exposure and management

A broad review of the issues as perceived by an eminent acoustical expert who has been engaged on this issue for more than 20 years.

Miller, N. P. 2008. U.S. National parks and management of park soundscapes: A review. Applied Acoustics 69:77–92.

■ ■ ■

Another review of the issues, which offers an interesting perspective at an earlier historical period.

Sutherland, L. C. 1999. Natural quiet: An endangered environment: How to measure, evaluate, and preserve it. Noise Control Engineering Journal 47(3):82–86.

■ ■ ■

This survey revealed that 44% of the park units indicated that the 1999 level of overflight activity was either a moderate or a major concern. Thirty-six percent of park units indicated they had received formal or informal complaints about overflight activity from visitors.

Voorhees, P. H., and L. Krey. 1999. Prevalence and severity of overflights on U.S. national parks: Results of the 1998 survey of national park superintendents. Noise Control Engineering Journal 47(3):107–111.

■ ■ ■

Wind turbines and off-road vehicles

Wind turbine noise is shown to evoke annoyance at much lower sound exposure levels (measured as an Leq in dB[A]) than aircraft, road traffic, or railways.

Pederson, E., and K. P. Waye. 2004. Perception and annoyance due to wind turbine noise—a dose-response relationship. Journal of the Acoustical Society of America 116:3460–3470.

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Science Notes

Applying community noise metrics in parks

By Kurt M. Fristrup

NOISE MANAGEMENT IS AN EMERGING practice for the National Park Service (NPS), so evaluating community noise standards in the context of the NPS mission offers opportunities to recognize shared priorities as well as noise criteria that are inappropriate for park settings. Unfortunately, the United States has a checkered history of noise management (Holger 2003), which has hampered development of consistent standards and practices. The Noise Control Act of 1972 and the Quiet Communities Act of 1978 assigned coordination of national noise management efforts to the U.S. Environmental Protection Agency (EPA), but funding for the EPA Noise Control Division was eliminated in 1982 to shift responsibility of noise regulation to state and local governments. At the federal level, the U.S. Department of Transportation retained the paradoxical responsibility of managing transportation noise, even though their primary mission is expanding the capacity and coverage of transportation networks. Despite the paucity of useful developments in the past 30 years, three measures of noise impacts that emerged in the 1970s are applicable today: speech interference, classroom acoustical standards, and sleep interruption.

Virtually all community noise impact criteria use A-weighting to summarize the aggregate effects of sound energy across the entire audible spectrum. A-weighting, expressed in units of dB(A) (or dBA), discounts sounds below 1 kHz and above 5 kHz in accordance with decreased human hearing sensitivity at low and high frequencies. Aggregate noise level measures like dB(A) ignore the capacity of humans to selectively detect sounds at different frequencies. However, dB(A) provides a reasonable basis of comparison when the sounds have similar power spectra, or a similar distribution of energy of sounds across frequency. Transportation noise sources generate most of their sound energy in frequencies below 1 kHz, so dB(A) values for cars, trucks, motorcycles, boats, snowmobiles, and aircraft are comparable. However, dB(A) measurements from natural settings are often dominated by the sounds of birds, frogs, and insects. It is inappropriate to treat these sounds as "noise" in park units, and it is acoustically incorrect to interpret the resulting dB(A) levels as being comparable to—or likely to mask perception of—transportation noise. For these reasons, the NPS Natural Sounds Program recommends excluding sound energy above 1 kHz from environmental dB(A) measurements, and is working with national standards committees to codify this practice.

Speech interference criteria are relevant to all park management zones. Park staff and visitors should reasonably expect to communicate in most conversational settings without having to raise their voices. The EPA published guidelines to realize 95% sentence intelligibility for conversational speech as a function of vocal effort, distance, and noise level (EPA 1974, table D1):

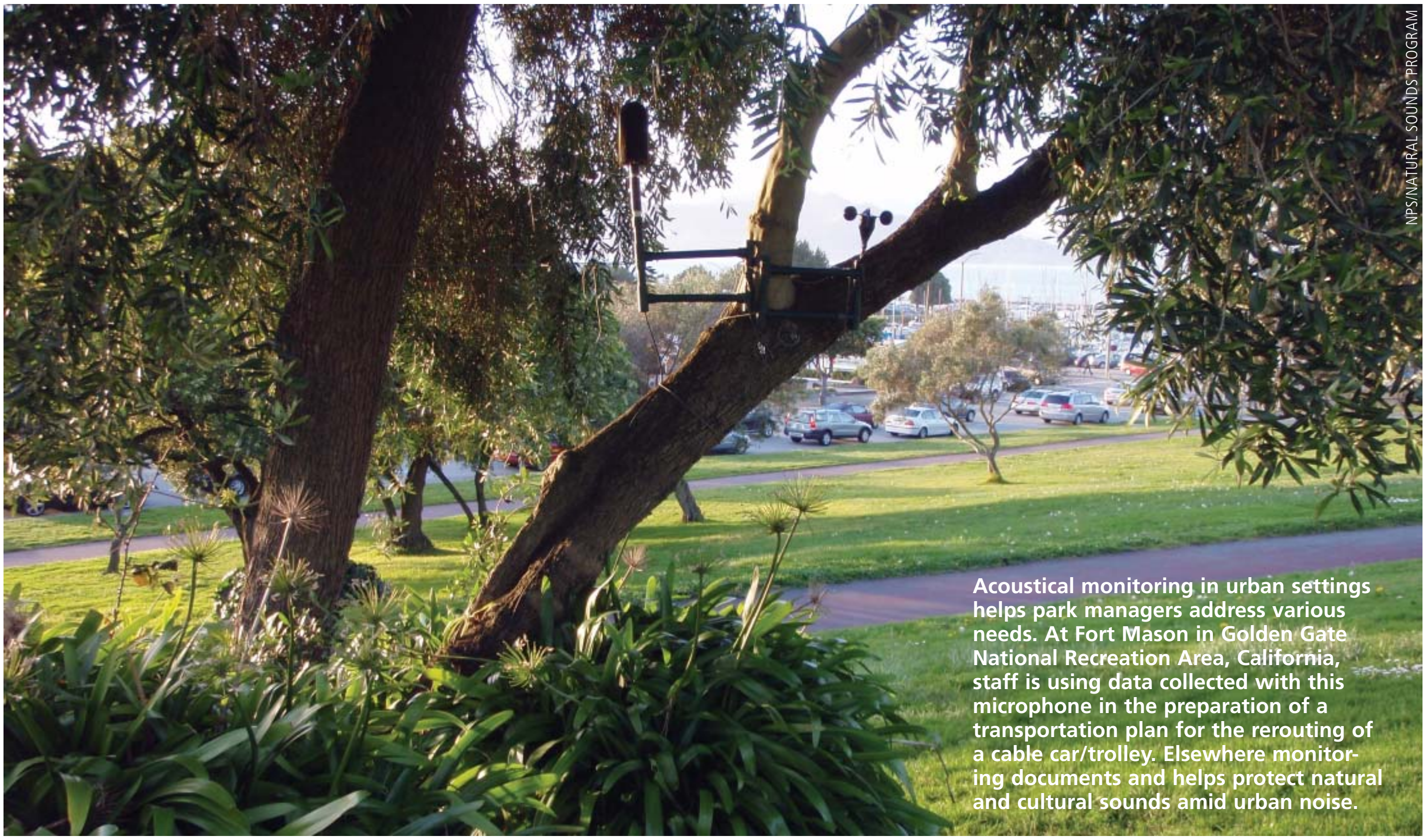
Table D1. Steady A-weighted noise levels that allow communications with 95% sentence intelligibility over various distances outdoors for different voice levels

	Communication distance (meter)					
Voice level	**0.5**	**1**	**2**	**3**	**4**	**5**
Normal voice (dB)	72	66	60	56	54	52
Raised voice (dB)	78	72	66	62	60	58

Source: EPA 1974.

These values can be extended to longer distances by subtracting a factor of $20*\log_{10}(R/Rref)$ from any cell's associated decibel threshold (R represents the longer distance). For example, extending the italicized threshold of 66 dB at which people have to raise their voices to be understood at 2 m (6.6 ft) distance to 10 m (32.8 ft) distance results in a threshold of 52 dB: $66-20*\log_{10}(10/2)$. Desired conversational settings can be specified in terms of limited numbers or duration of interruptions, or desired intervals free from interruptions. Speech interference metrics are being utilized in ongoing air tour and soundscape management plans to assert that acute noise events that interrupt conversations should be rare.

Speech interference criteria can be applied to park ranger presentations because interruptions will compromise interpretive goals and the integrity of these settings.


NPS/NATURAL SOUNDS PROGRAM

Acoustical monitoring in urban settings helps park managers address various needs. At Fort Mason in Golden Gate National Recreation Area, California, staff is using data collected with this microphone in the preparation of a transportation plan for the rerouting of a cable car/trolley. Elsewhere monitoring documents and helps protect natural and cultural sounds amid urban noise.

Another relevant criterion is the ANSI (American National Standards Institute) standard for appropriate acoustical conditions in classrooms (ANSI S12.60). Empty classrooms should have sound levels below 35 dB(A) to provide good conditions for learning. This also acknowledges that children—especially those less than 8 years of age—have difficulty distinguishing speech in noise.

Noise also can disturb sleep. ANSI standard S12.9-2008 provides formulae for estimating awakenings from a sequence of noise events. Events louder than 45 dB(A) will waken some people; events louder than 35 dB(A) cause increases in heart rate and blood pressure (Haralabdis et al. 2008). These criteria were based on studies of people in familiar settings. In park lodging, and especially in campsites, visitors will be much more prone to awakening because the soundscape will be unfamiliar and they may feel less secure.

The National Park Service has a relatively protective noise regulation for all motorized equipment (including motor vehicles) and audio devices (36CFR2.12), which requires sound levels at a 50-foot distance to be below 60 dB(A) and reasonable for the activity in the park setting. Sound level meters are rare outside of the Natural Sounds Program, so the reasonableness criterion is the probable basis for enforcement. This protective regulation contrasts with two others (36CFR2.18, 36CFR3.7) that allow a snowmobile or boat to radiate as much noise as 63 or 446 automobiles, respectively, even though sound carries farther in the environments used by these vehicles. This inconsistency illustrates an important point: many principles and practices from community noise management can be applied in park settings, but it is crucial to carefully reevaluate each one in the context of the desired future conditions we intend to preserve or restore in park units.

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Relating wildlife behavioral responses to noise to ecological consequences

By Jesse R. Barber and Kurt M. Fristrup

THE EFFECTS OF NOISE ON WILDLIFE are most commonly documented by observations of behavioral responses, because experimental trials are brief and readily replicated. Studies that document changes in population density or spatial distribution are more difficult and less common, but they address ecological issues that relate directly to resource conservation. Can focal, behavioral studies provide reliable indications of ecological consequences of noise? Yes, if the immediate response measure relates directly to demographic and ecological processes.

For example, recent data collected on the effects of noise on breeding boreal songbirds showed that pairing success was significantly reduced in noisy environments around natural gas compressor stations (Habib et al. 2007). Noisy areas were disproportionately populated by younger males, and they were less successful at attracting mates than were young males in quiet areas. Subsequent survey work by the same laboratory confirmed the expected ecological consequences: passerine birds had a density 1.5 times higher in quiet control sites than they did near loud compressor stations (Bayne et al. 2008).

Two sets of studies on the responses of ungulates to anthropogenic disturbance events associated with high levels of noise (roads, oil/gas extraction, and military training) illustrate misleading inferences from small spatial-scale, focal studies. Decades of research have been devoted to the responses of caribou (*Rangifer tarandus*) to human activities; 85 of these studies were reviewed by Vistnes and Nellemann (2007). They found that only 13% of focal, behavioral studies document significant responses. This suggests low-frequency impacts, and the evidence could be dismissed as equivocal. However, 83% of the studies conducted over large spatial scales document substantial negative effects. Within 5 kilometers (3 mi) of human infrastructure or activities, caribou reduce habitat utilization by 50–95% (see photo). Studies of endangered Sonoran pronghorn (*Antilocapra americana sonoriensis*) yielded a similar pattern: minimal behavioral responses to noise (Krausman et al. 2004), but landscape-scale analysis revealed significant preference for quiet and avoidance of noise (Krausman et al. 2004).

Caribou roam the Arctic tundra of Alaska's North Slope along the 414-mile Dalton Highway, also known as the Haul Road. Research suggests caribou reduce their activity 50–95% within 3 miles of human infrastructure and activities.

Failure to observe behavioral responses to noise during focal experiments does not provide a strong basis for dismissing ecological impacts. These studies indicate the importance of selecting behavioral response metrics that are intimately related

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Tolerating noise and the ecological costs of "habituation"

Jesse R. Barber, Frank Turina, and Kurt M. Fristrup

ANIMALS ARE SAID TO BE HABITUATED when their response to a novel stimulus diminishes over time. Habituation can be viewed as adaptive when the stimulus is irrelevant to the animals. Animals that exhibit tolerance of noise are often cited as evidence that noise impacts to wildlife are transient and of neutral ecological consequence. Both theory and observations refute the equation of noise tolerance with absence of impact.

At the Monkey Mia resort in Australia, a population of bottlenose dolphins (*Tursiops* spp.) has been exposed to tourism for more than 40 years. Experimental studies of dolphin reactions to boats documented much stronger responses by dolphins outside of tourist areas than inside tourist areas (Bejder et al. 2006). Two decades of surveys at these sites documented a decrease in the dolphin population inside tourist areas coinciding with an increase outside these areas. Dolphins have long generation intervals, so these studies implicate displacement of sensitive individuals, not habituation.

An apparent increase in noise tolerance may actually indicate more severe constraints on animal behavior (Gill et al. 2001). Declining foraging success and body condition can cause animals to diminish their responses to disturbance stimuli because they cannot afford decreased feeding rates (Stillman and Goss-Custard 2002). Recent work with turnstones (*Arenaria interpres*, see photo) has shown that birds whose food resources were experimentally supplemented flushed earlier and flew farther when approached (Beale and Monaghan 2004).

If animals demonstrate behavioral or distributional changes to acoustical disturbance, management action can be taken. However, in the absence of clear impacts, we suggest managers strive to ensure that (1) sensitive individuals have not already been displaced; (2) decreased body condition, critical habitat needs, social forces, lack of habitat experience, and/or expensive investment in territory formation are not preventing animals from reacting to the disturbance (Bejder et al. 2009); and (3) alternative explanations are not available. For example, in Grand Teton National Park, mother moose (*Alces alces*) have been giving birth closer to the road over the last 10 years. In the absence of data indicating that this shift protects moose calves from recolonizing, road-averse grizzly bears (*Ursus arctos*) exhibiting this behavioral pattern may have been interpreted as evidence for habituation to the roadway (Berger 2007).

Managers should minimize wildlife exposure to noise and avoid habituation to noise wherever possible. However, in situations where acoustical disturbances to wildlife cannot be avoided, park managers should consider structuring human activities to foster habituation. A predictable timetable enhances opportunities for learning. Animals can distinguish between routine and anomalous occurrences of human noise; they might productively utilize habitats that they would otherwise avoid, or perform critical activities during times of reduced human presence. Scheduling can provide more control over interactions between visitors and wildlife, and offer more reliable opportunities to view wildlife under less perturbed conditions. Given increasing evidence of animals avoiding traffic on roads (e.g., Gagnon et al. 2005; Waller and Servheen 2005; Kerth and Melber 2009), scheduling of visitor access to protected lands will likely increase habitat connectivity, reduce wildlife collisions (thus increasing visitor safety), and increase overall habitat quality in the last of our wild places.

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Ruddy turnstones forage by probing and flipping over stones along rocky shores in search of insects and other invertebrate prey. Animals that depend on specialized habitats may become tolerant of disturbance owing to lack of readily available, alternative habitats. In contrast to habituation, tolerance may carry ecological costs.

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CONTINUED FROM PAGE 23

Demographically important behaviors that occur during limited times of the year—breeding, provisioning offspring, defending offspring against predation—are likely to provide persuasive positive evidence of noise impacts.

to population consequences. However, negative evidence of behavioral responses to noise, even with the best metrics, cannot be as decisively interpreted. The prevalence of documented noise impacts suggests the need for adaptive management at the appropriate spatial scale even when initial studies indicate no significant problems.

What about behavioral responses that are not accompanied by population consequences? Fishery or game resource managers would dismiss these impacts, but the National Park Service is required to preserve for future generations the opportunity to experience unimpaired wildlife resources. Shifts in habitat use and activity schedules may render wildlife less accessible to visitors, and behavioral adaptations to noise constitute degradation of the authentic ecological conditions that parks were created to preserve.

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State of Science

Conserving the wild life therein: Protecting park fauna from anthropogenic noise

Jesse R. Barber, Kurt M. Fristrup, Casey L. Brown, Amanda R. Hardy, Lisa M. Angeloni, and Kevin R. Crooks

HABITAT DESTRUCTION AND FRAGMENtation are the greatest threats to wildlife and the major causes of species extinction (Wilcove et al. 1998; Crooks and Sanjayan 2006). National parks are largely protected from the wholesale conversion of land to human uses, but parks are not entirely protected from habitat degradation. Climate change, altered atmospheric and hydrologic conditions, and disrupted migration and dispersal pathways are examples of issues that transcend park boundaries. To these we can add another pervasive factor that has not received the same level of attention. Noise knows no boundaries, and national park units are experiencing substantial degradation of their acoustic environments from largely uncontrolled external activities as well as internal visitor use and park management.

Concern for wildlife

Why should we be concerned about noise impacts to wildlife? Hearing provides panoramic awareness of an organism's surroundings. This alerting sense is vital. In contrast to vision, hearing continues to function in sleeping or hibernating animals. Evolution reinforces this point: many species in a variety of lineages have lost sight, but no cases of lost hearing are known (Fong et al. 1995). Hearing almost certainly evolved before intentional vocalization (Fay and Popper 2000), providing environmental surveillance before being repurposed for communication. Acoustical cues play a dominant role in sexual communication, territory defense, habitat quality assessment, and predator-prey interactions (fig. 1). We do not understand all the consequences, but rising background sound levels due to anthropogenic noise raise profound concerns for ecosystem management.

The world is getting louder. Noise from transportation networks, development (including energy, urban and industrial), and recreational activities is increasing faster than population size. For example, between 1970 and 2007, the U.S. population increased by approximately one-third (U.S. Census Bureau 2007), but traffic on U.S. roads nearly tripled, to almost 5 trillion vehicle kilometers (3 trillion miles) per year (U.S. Federal Highway Administration 2008). Similar trends have also been observed in marine ecosystems and have provoked reviews of noise impacts on marine animals (Popper and Hastings 2009; Nowacek et al. 2007; Weilgart 2007).

Park transportation corridors presently have median ambient sound levels that are more than four orders of magnitude higher than the natural condition (fig. 2, page 28). Remote backcountry areas are not immune. Air transportation noise blankets the entire continent, and high-traffic corridors can generate substantial noise on the ground. During peak traffic hours, aircraft are audible at the Snow Flats backcountry site in Yosemite National Park nearly 70% of the time (fig. 2B, page 28). The median sound level is elevated 3 to 5 decibels (dB) during these hours. Decibels are a logarithmic scale, and small changes can have important consequences. A 5 dB increase in background sound level (in the frequency band of the acoustic signal) means prey species could experience a 45% reduction in the distance at which they can hear a predator approaching, and predators that hunt using acoustic cues might experience a 70% reduction in search area. Similar calculations apply to animal communication.

Noise knows no boundaries, and national park units are experiencing substantial degradation of their acoustic environments from largely uncontrolled external activities as well as internal visitor use and park management.

The problem with noise

High levels of noise have been shown to affect human health, and similar findings document physiological impacts to wildlife from noise, including temporary and permanent hearing loss (Bowles 1995; Dooling and Popper 2007; Jarup et al. 2008). Because of the relatively high levels of exposure required, these effects will be unlikely in park settings, but noise does contribute to wildlife disturbance in response to human stimuli. Anthropogenic intrusions are perceived by animals as predation risk. These disturbances evoke antipredator behaviors and interfere with other activities that enhance fitness (e.g., foraging, parental care, and mating). When

Figure 1. A great gray owl (*Strix nebulosa*) plunges through snow to catch its prey. Many owls use sound as the only cue to find prey, and the pronounced facial disk of this owl species amplifies the quiet rustling noises of voles and shrews moving underneath snow. The great gray owl is found in national parks such as Yosemite, Glacier, Yellowstone, Voyageurs, and Wrangell–St. Elias.

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disturbances are sufficiently frequent, population consequences may result (reviewed in Knight and Gutzwiller 1995 and Frid and Dill 2002). The role that sounds play in stimulating a disturbance response to human activities depends upon species and context, but it is probable that degraded listening conditions amplify wildlife responses to all perceived predation threats (Rabin et al. 2006).

Animals need not perceive noise sources to be affected. When noise elevates ambient sound levels, the capacity to detect acoustic signals of interest is degraded. Interference of signal detection and recognition due to noise is called "masking." Masking is important for parks because seemingly modest increases in ambient sound levels can have substantial effects. Masking can degrade acoustical communication and auditory awareness of the adventitious sounds of nature and fundamentally alter interactions between organisms.

Numerous studies implicating noise as a problem for animals have reported reduced bird densities near roadways (for review see Reijnen and Foppen 2006). An extensive study conducted in the Netherlands found that 26 of 43 (60%) woodland bird species showed reduced numbers near roads (Reijnen et al. 1995). This work, though suggestive, did not isolate noise from other possible factors associated with transportation corridors (e.g., collisions, chemical pollution, increased predation,

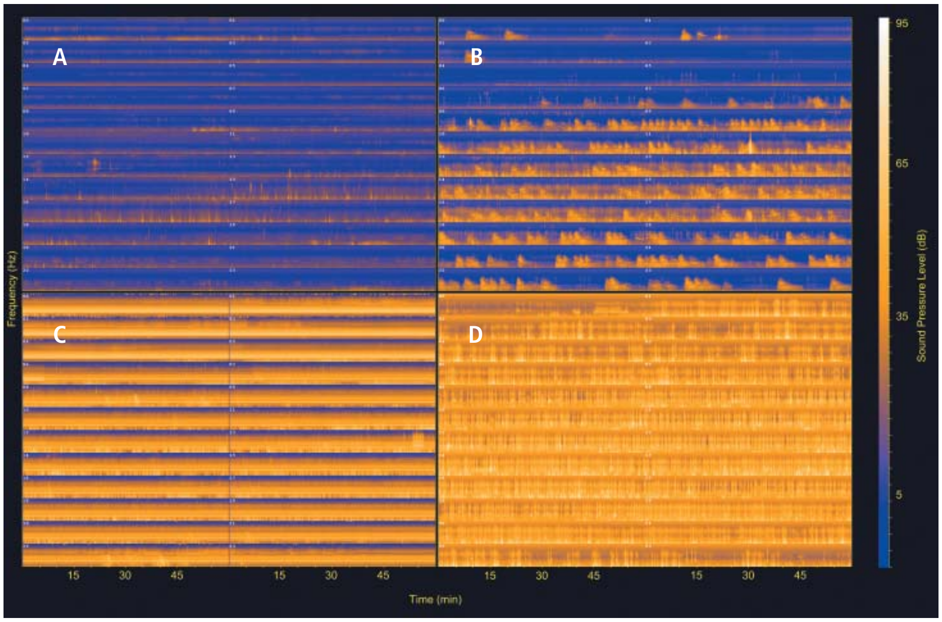


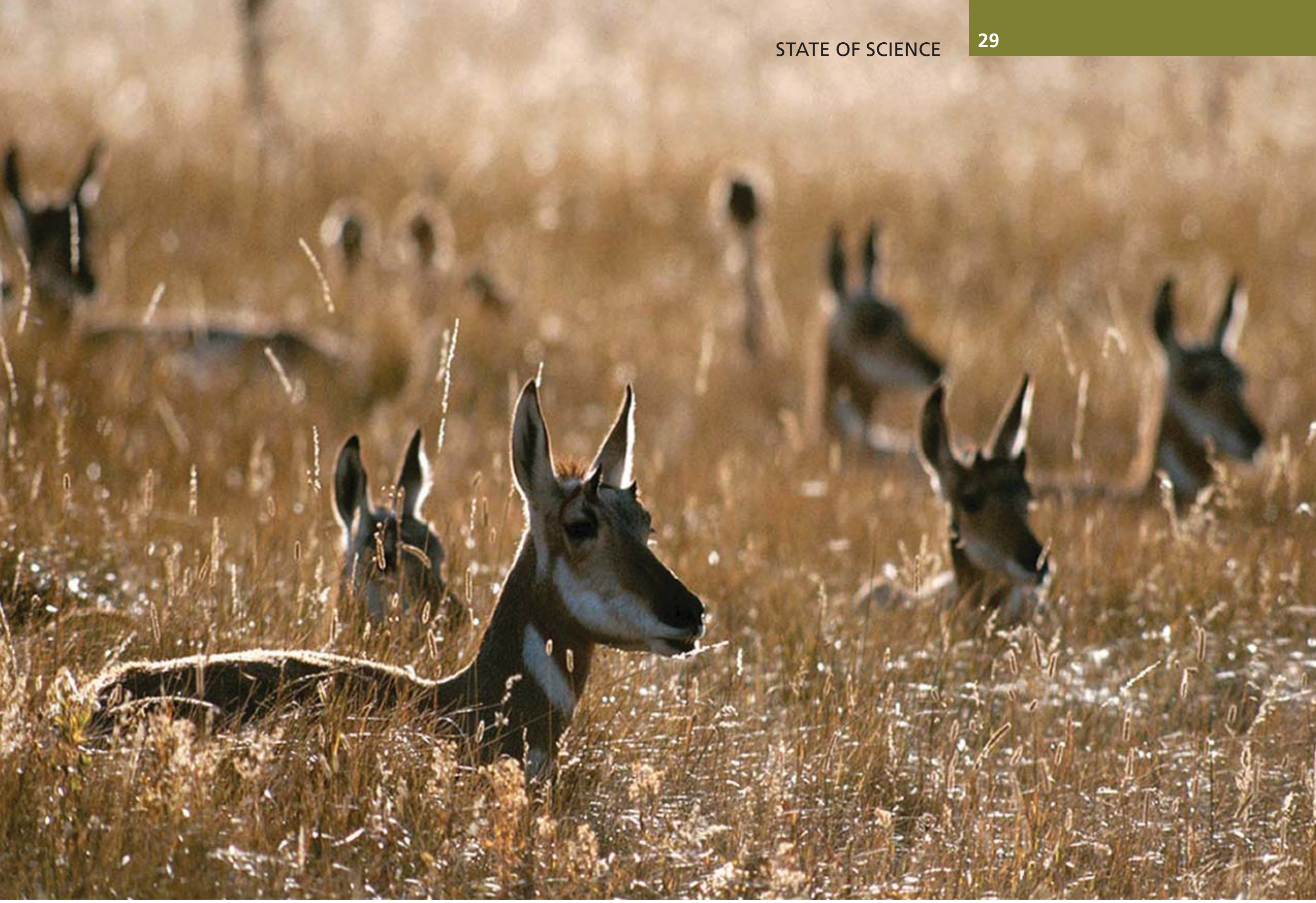
Figure 2. Twenty-four-hour spectrograms of four protected areas: (A) Kenai Fjords National Park and Preserve, Alaska; (B) Yosemite National Park, California; (C) Organ Pipe Cactus National Monument, Arizona; and (D) Rocky Mountain National Park, Colorado. Each panel displays one-third octave sound pressure levels, with two hours represented horizontally in each of 12 rows. Frequency is shown on the *y* axis as a logarithmic scale extending from 12.5 Hz to 20 kHz, with the vertical midpoint of each row corresponding to 500 Hz. The *z* axis (color) describes sound pressure levels in dB (unweighted), indicated by the color key at the right. The lowest volume one-third octave levels are below 0 dB, the nominal threshold of human hearing. Panel *A* contains only one intrusion from human-caused noise, a propeller airplane at 12:20 p.m. *B* is dominated by high-altitude jet signatures. Clear examples can be seen between midnight and 12:30 a.m. *C* was recorded approximately 35 m (115 ft) from a generator used by a mobile border patrol camp. *D* illustrates traffic noise recorded 15 m (49 ft) from Trail Ridge Road during a weekend event featuring high levels of motorcycle traffic. Background sound levels at this site were elevated by a nearby river.

and invasive species along edges). However, these effects extended over a mile into the forest, pointing to noise as the likely cause. Later work confirmed these effects and contributed a significant finding: birds with higher-frequency calls were less likely to avoid roadways than birds with lower-frequency calls (Rheindt 2003). It seems that masking of birdcalls by predominantly low-frequency traffic noise may account for some of the observed reductions in bird density near roads.

This finding was published the same year that European researchers reported great tits (*Parus major*) significantly increasing the frequency of their songs in the cacophony of urban noise (Slabbekoorn and Peet 2003). Subsequently, multiple bird species have been shown to increase the frequency of their songs in order to be heard above the din of human-made noise (for a review see Brumm and Slabbekoorn 2005). Some birds have even resorted to calling at night, when urban centers are quieter (Fuller et al. 2007).

Further evidence of the impacts of anthropogenic noise on animals comes from oil and gas fields in Canada's boreal forest. Researchers took advantage of the co-occurrence of noise-generating compressor stations and noiseless well pads. Both of these installations were situated in 2- to 5-acre (0.8 to 2.0 ha) clearings with dirt access roads that were rarely used. This system allowed for elegant control of edge effects and other confounding variables associated with road studies. The research showed that ovenbird (*Seiurus aurocapilla*) pairing success is significantly reduced in the presence of noise (Habib et al. 2007) and passerine birds have a density 1.5 times higher in quiet control sites than near compressor stations (Bayne et al. 2008). Similar avian work in northwestern New Mexico found reduced nesting species richness near loud compressor stations (compared to controls) but in contrast to the Canadian group, no reduction in overall nesting density (Francis et al. 2009). This difference appears to be driven by site preference (e.g., three species nested only in loud sites and 14 only in quiet sites). The major next predator in the study area, the western scrub jay (*Aphelocoma californica*), was significantly more likely to occupy quiet sites, which might explain the nest density data. The study also found that the two bird species most strongly

Oil and gas development platforms may disturb a limited area of vegetation, but the noise footprint is much larger. The quiet spaces within a developed field may be too small and too far apart to support species that are sensitive to noise, and loud areas may form barriers to migration and dispersal.



associated with control sites produce low-frequency communication calls (Francis et al. 2009). These data suggest masking as an explanatory factor for these patterns and highlight the potential complexity of the relationship between noise exposure and the structure and function of ecological systems.

Additional support that animals change their distributions in response to anthropogenic noise comes from the Sonoran pronghorn (*Antilocapra americana sonoriensis*). These endangered ungulates preferentially use quiet areas and avoid loud areas created by military jet overflights (Landon et al. 2003). The behavioral evidence in this review suggests it is likely that many species would avoid high background sound levels. This response could exacerbate habitat fragmentation and connectivity. For example, oil and gas development platforms may disturb a limited area of vegetation, but the noise footprint is much larger. The quiet spaces within a developed field may be too small and too far apart to support species that are sensitive to noise, and loud areas may form barriers to migration and dispersal.

Frogs are also affected by anthropogenic noise. In the lab, when traffic noise is played back to gray treefrog (*Hyla chrysoscelis*) females as they attempt to locate the source of male calls, it takes them longer to do so and they are significantly less successful in correctly orienting to the male signal (Bee and Swanson 2007). The European tree frog (*Hyla arborea*) decreases its calling activity in played-back traffic noise (Lengagne 2008). This work further demonstrates that these frogs are unable to adjust the frequency or duration of their calls to increase signal transmission, even at very high noise intensities.

This last point is particularly salient. Adjusting characteristics of communication signals to prevent masking has been demonstrated only in birds, primates, cetaceans, and one squirrel species (reviewed in Brumm and Slabbekoorn 2005; Nowacek et al. 2007; and Weilgart 2007). It is likely that many species within these groups, and other entire groups of organisms (like insects), are unable to adjust the structure of their sounds to cope with noise. These differences in vocal adaptability could explain why some species do well in loud environments and others do poorly.

Compelling evidence also exists that anthropogenic noise interferes with predator-prey interactions. Laboratory work has shown that gleaning bats, predators that use prey-generated sounds to

Figure 3. Like ground squirrels, pronghorn (*Antilocapra americana*) shown here in Yellowstone National Park may compensate for diminished hearing in the presence of noise by vigilantly scanning their surroundings for visual signs of danger.

Anthropogenic intrusions are perceived by animals as predation risk. These disturbances evoke antipredator behaviors and interfere with other activities that enhance fitness (e.g., foraging, parental care, and mating).

localize terrestrial insects, avoid hunting in areas with road noise (Schaub et al. 2008). When predator-elicited alarm calls are played back to California ground squirrels (*Spermophilus beecheyi*), they show a greater increase in vigilance behavior during anthropogenic noise, under power-generating wind turbines, than during quiet control conditions (Rabin et al. 2006). Further study of vigilance behaviors in noise comes from controlled laboratory work with foraging chaffinches (*Fringilla coelebs*). In the presence of noise these birds decrease the interval between head-up scanning bouts, which results in fewer pecks and thus reduced food intake—costs that may have population consequences (Quinn et al. 2006). It seems likely that these increased antipredator behaviors are the result of attempted visual compensation for lost auditory awareness (fig. 3, previous page).

Managing soundscapes for people and wildlife

We are currently addressing the effects of anthropogenic noise on animal ecology on multiple scales. Grand Teton National Park in Wyoming recently adopted a transportation plan that includes establishing paved multiuse pathways along some of the park's existing motorways; the plan also entails field studies to assess the potential impacts of pathway construction and activities on wildlife. We have initiated a four-year, NPS-funded study to assess how the construction and use of the pathway affect ungulate distribution and behavior as well as visitor interactions with wildlife, focusing on elk and pronghorn. We are complementing this fieldwork with acoustic monitoring to record anthropogenic noise in the study area. This work will address major questions in the study of anthropogenic noise impacts on wildlife: To what extent are human disturbance events augmented by noise? Will animals change their distributions in greater levels of anthropogenic disturbance and noise? And what role does the reduced auditory awareness imposed by anthropogenic masking play in the vigilance-foraging trade-off?

In a second project at Grand Teton National Park, we are measuring the masked hearing thresholds of birds in relation to noise from road and aircraft traffic. A significant body of literature addresses the hearing ability of birds in the laboratory using artificial noise sources (see Dooling and Popper 2007), but thresholds have not been measured under unrestrained conditions in natural environments. These field studies will reveal the extent to which wild birds are able to realize some release from masking by changing their behavior and directing their attention. To collect these data we are playing biologically critical signals to mixed-flock songbird species along the Snake River corridor and videotaping their behavioral responses. We are reconstructing the three-dimensional position of each bird to accurately model the signal and noise levels at the bird's location. Results from this work will document the masking effects of low-frequency anthropogenic noise on animal signals and improve noise impact metrics.

Although the outcome of new research will inform park management, these results are not needed to begin taking action. The available evidence powerfully implicates anthropogenic noise as a threat to sexual communication, spatial distributions, and predator/prey interactions, and thus to animal populations. These are direct threats to the NPS mission to "conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations" (NPS Organic Act, 1916). Parks can design transportation networks and manage park operations to minimize noise impacts to sensitive resources. Concession contracts and commercial use authorizations can be drafted to incorporate noise mitigation requirements. Park interpretive materials can promote greater understanding of the important role that park soundscapes play and encourage visitors to listen more actively and reduce their noise. The 2006 revision of NPS *Management Policies* states that when conflicts arise between the protection of resources and their use, "conservation will be predominant." In those instances where noise mitigation is politically and economically daunting, the National Park Service must be willing to implement management actions that reduce the consequential effects of masking on wildlife.

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Features

Measuring and monitoring soundscapes in the national parks

By Kurt Fristrup, Damon Joyce, and Emma Lynch

ATTENTIVE LISTENING IS AN immersive experience, and in national park settings it can amplify visitor awareness of resources and their value. Noise disrupts this experience. Accordingly, the sounds of a park unit and superb conditions for hearing them are signatures of park integrity and authenticity. Quiet environments encourage relaxation, observation, learning, and contemplation. For indoor settings, these values are expressed in the protective architectural noise standards that apply to libraries, classrooms, concert venues, and churches (American National Standards Institute, Standard S12.2). In protected natural areas, noise-free environments also provide outstanding opportunities to perceive and identify the sounds of nature, encouraging visitors to expand their auditory as well as visual horizons.

The compelling benefits of natural quiet for park visitors reinforce the importance of noise management for preserving and restoring ecological integrity. Acoustical communication is vital for many species, and hearing alerts animals to nearby events, even when they are sleeping.

Acoustic monitoring is essential for managing noise, and it is a powerful tool to document patterns of wildlife activity and visitor use. Many animals reveal their presence and advertise their behavior using sound. Unattended recording is noninvasive: weeks of data can be obtained with minimal human presence and instrument footprint, and animals do not have to be captured or tagged. Audio recordings can chronicle changes in wildlife behavior in response to visitor use or revised management practices. Acoustic monitoring is an efficient way to track almost any form of traffic: hikers, all-terrain vehicles, snowmobiles, boats, automobiles (and their types), and aircraft. Finally, acoustic monitoring can identify sources of noise and document daily and seasonal patterns in ambient sound levels.

Figure 1. Winter acoustical monitoring at the Lyell Fork of the Tuolumne River in Yosemite National Park produced basic sound data collected through attentive listening.

Basic sound monitoring with a PDA

Sound fluctuates more rapidly than any other environmental variable monitored by the National Park Service—thousands of times a second—but simple methods of collecting data are available. Attentive listeners can identify audible sounds, noting the start and stop times of each. In its simplest form, this monitoring can be accomplished with a watch, notebook, *Audio recordings can chronicle changes in wildlife behavior in response to visitor use or revised management practices.*

Table 1. Winter audibility report generated from Palm PDA monitoring at Lyell Fork of the Tuolumne River, Yosemite National Park

ID	Sound	Percentage of time sound audible	Max event duration (seconds)	Mean event duration (seconds)	Number of events
1	Aircraft, unknown	0.5	108	108	1
1.1	Aircraft, jet	51.5	552	137	88
1.2	Aircraft, propeller	5.7	382	88	15
G100	All aircraft	53.4			
8.3	Skiing	0.4	52	44	2
20	Nonnatural, other/unknown	0.0	6	3	3
21	Wind	31.7	270	47	158
22	Water sounds	0.0	1	1	1
22.1	Rain/Fog drip	0.2	13	3	14
22.3	Snowfall	1.0	22	3	93
25	Bird	16.0	592	23	160
40	Other, natural	13.4	200	7	452
NFI	Noise-free interval	N/A	1,059	123	88
G2000	All human-made sources	53.6			
G4000	All natural sources	50.5			

This table summarizes 29 hours of audibility data collected by Bruce Carter and Tracey Wiese, backcountry rangers at Yosemite National Park. Percentage of time audible documents how often sounds are present, and event-free intervals document the gaps between anthropogenic noise events.

and pencil. To expedite collection and transcription of data, the National Park Service has developed sound logging software that runs on Palm PDAs (personal digital assistants). The listener taps buttons on the PDA screen to indicate the start and end of identifiable sounds. With practice, many overlapping sound events can be monitored. The data are easily downloaded (using Palm HotSync software) into a Microsoft Access database that automatically analyzes the data and generates summary reports. PDA audibility logging is an inexpensive way of engaging volunteers, youth groups, and employees from all disciplines in attentive listening exercises. These foster understanding of parks' acoustic resources, inspire the protection of "natural quiet," and produce valuable monitoring data.

The list of sounds available to assign to PDA "buttons" includes all North American bird species, making these units

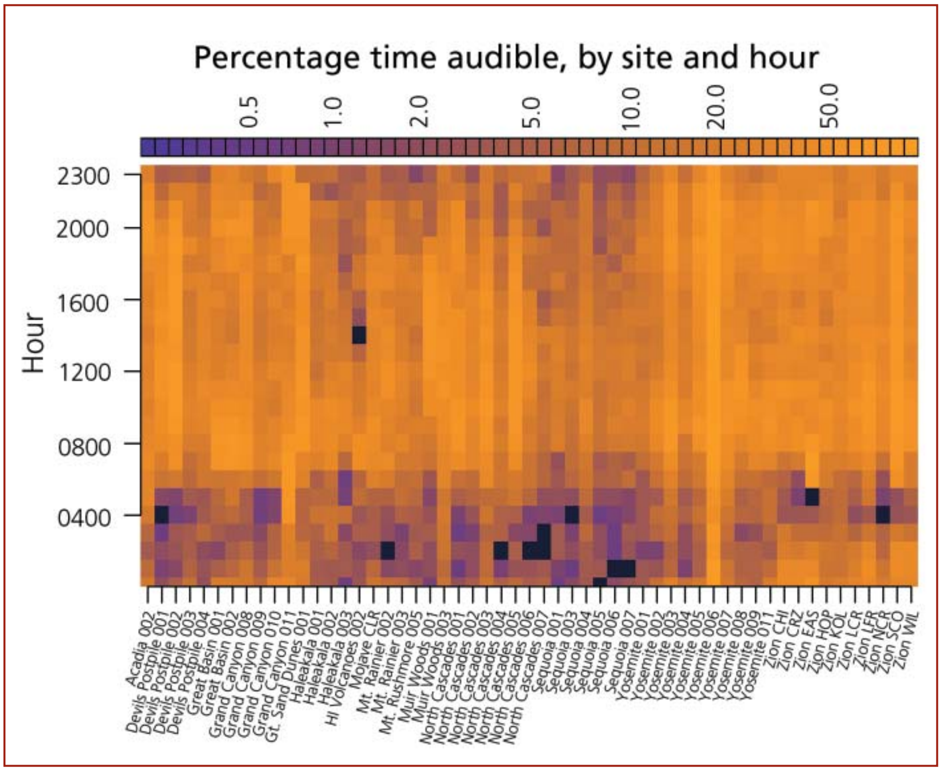

Figure 2. This spectrogram presents the audibility of noise at 55 sites in 13 national park units. Warmer colors indicate a higher percentage of time audible value.

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useful for acoustic avian surveys. The NPS Natural Sounds Program can customize the sound buttons to serve other applications. The PDA records the start and stop time of each sound event, so several acoustic metrics can be derived from these data: percentage of time audible, noise-free interval, number of events, and event durations. Figure 1 depicts PDA-based data collection in winter at Lyell Fork on the Tuolumne River, Yosemite National Park (California), and table 1 presents the results generated from this site.

Figure 2 shows how often noise is audible in 14 national park units. This picture is dominated by yellow blocks, indicating that noise from human activities was audible more than 20% of the time at most sites and hours. Many of these sites are in backcountry or wilderness areas. Noise is a pervasive pollutant in the National Park System.

Figure 3. Acoustic monitoring station deployed at Great Sand Dunes National Park and Preserve, Colorado. The anemometer on the right is used to determine when wind speeds are too high to obtain reliable measurements. The microphone on the left is topped with a metal spike to discourage birds from perching on the foam windscreen. The unit costs about $10,000. Data collected at this site were used to document extraordinarily quiet conditions in the park, which were important in subsequent discussions regarding oil and gas development near the park (NPS/Emma Lynch).

Greater sophistication in monitoring

For human listeners, one-third octave approximates how close two signals can be in frequency before one begins to interfere with perception of the other. This spectral resolution is needed to measure or model the audibility of sounds for park visitors.

Audibility data describe the durations of sound events, but not their intensities. Consumer audio recorders and sound level meters offer many options to measure sound levels. The appropriate amount of data collection will balance complexity (and cost) against accuracy and extent of sampling. Systems can be surprisingly economical: almost 6 days of continuous audio recording can be obtained with a $30 solid-state, digital MP3 recorder, augmented by a couple of alkaline D batteries and a weather-resistant housing. Recorders with much longer endurance (up to 42 days) and higher-quality recordings can be obtained for $250 to $400, with an attendant increase in battery size and weight. Inventory and monitoring of sound sources, number and duration of natural and human sound events, and average length between noise events can all be obtained with low-cost digital recording units. Increases in flash memory storage and lightweight battery technology mean these devices can run for weeks without need for service, which is vital in remote backcountry locations. For situations in which acoustic modeling and compliance with standards are expected, a calibrated sound level meter may be required. ANSI type 2 systems suitable for cross-calibrating audio recorders can be obtained for less than $1,500.

The Larson-Davis 831 sound level meters used by the NPS Natural Sounds Program cost nearly $8,000; they are ANSI type 1 systems that can store data for several months. A picture of a Natural Sounds Program monitoring system deployed at Great Sand Dunes National Park and Preserve is presented in figure 3.

Part of the expense of these sound level meters is due to their capacity to make measurements in one-third octave spectral bands. For human listeners, one-third octave approximates how close two signals can be in frequency before one begins to interfere with perception of the other. This spectral resolution is needed to measure or model the audibility of sounds for park visitors. Musicians will recognize that one octave represents a doubling in frequency, and 11 doublings of frequency span the range of human hearing (10–20,000 Hz). Accordingly, NPS acoustic monitoring systems record 33 one-third-octave band level measurements every second, along with an A-weighted summary of aggregate sound level. A-weighted measurements (dB[A]) sum sound energy across the audio spectrum, with weights that account for reduced human sensitivity to low- and high-frequency sounds. The uses of A-weighted measurements are discussed in the "Community noise metrics" Science Notes article (page 21) in this issue. The sound level meter measures one-third-octave and A-weighted sound levels as decibels (dB) relative to a standard sound intensity of 10^{-12} watts/m^2. In partnership with Colorado State University's Electrical and Computer Engineering Department, sound pressure level monitors are being developed that will provide real-time data summaries using wireless telemetry.

In addition to providing a basis for modeling the audibility of sounds, one-third octave measurements can be used to create an image that portrays sound events with sufficient detail to identify many kinds of meteorological conditions and noise sources. The presence of wildlife sounds can also be indicated, though there is not enough detail to identify species. Four daily spectrograms are presented in figure 4, illustrating the variety and ubiquity of aircraft noise in national parks.

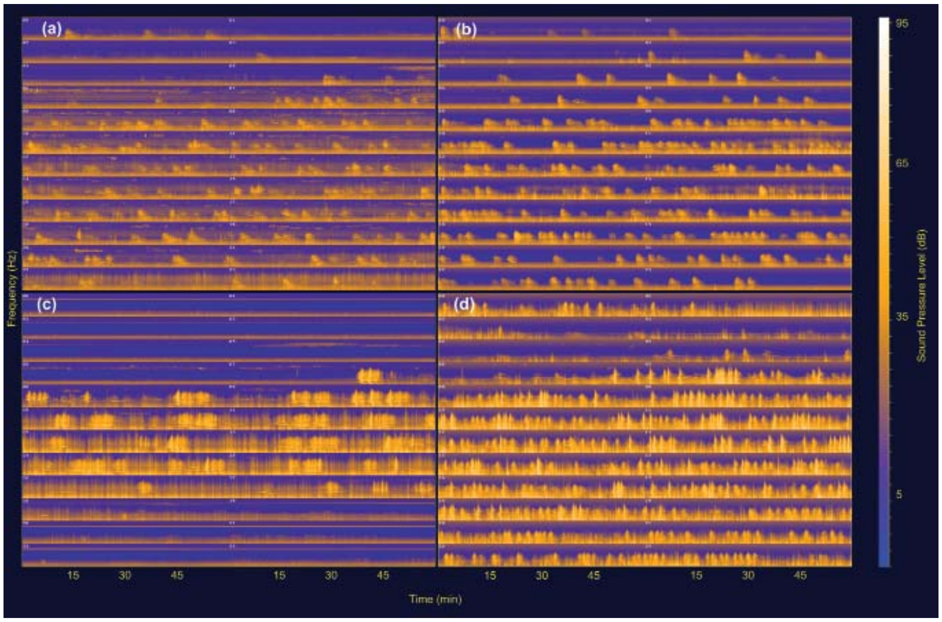

Figure 4. Daily spectrograms of sound levels at four national parks. Each row or band displays 2 hours of one-third-octave sound level data, starting at midnight at the upper left corner of each spectrogram and ending at midnight on the following day at the lower right corner. Minutes past the hour are noted on the X axis, with sound frequency (12.5–20,000 Hz) shown on the logarithmically scaled Y axis. Spectrogram a: A site on Mount Collins in Great Smoky Mountains National Park (Tennessee). Numerous high-altitude jet signatures are evident (examples at 0015, 0035, and 0050 hours), as well as some propeller-driven aircraft (examples near 0752, 0910, and 1235 hours). High-frequency sounds from the dawn chorus of birds begin near 0545 hours. Spectrogram b: Lyell Fork on the Tuolumne River in Yosemite National Park, California. High-altitude jet signatures are numerous, filling more than half of several daytime hours. Spectrogram c: Near Pu'u O'o in Hawai'i Volcanoes National Park. The sounds of helicopter air tours loitering near the eruption site begin at about 0740 and extend through 1700 hours. Spectrogram d: Indian Pass in Lake Mead National Recreation Area (Nevada). Numerous high-altitude jets and low-altitude air tour transportation flights obliterate natural acoustical conditions for all but a few hours of the day.

Visual analysis of acoustic data

The collection of several weeks of continuous audio and sound pressure levels has been made far easier by new instruments, but 73 million data points and 600 hours of audio is an overwhelming listening exercise. One solution is to subsample the data set, and listen to only a few hours of the several hundred. This is the current protocol for complex sites with many layered sound sources, such as Golden Gate National Recreation Area, an urban park unit.

Another method of presenting acoustic data is through the use of spectrograms, a type of plot showing sound level as a function of time and frequency. Traditionally, spectrograms are used to show fine detail in rapidly varying sounds, such as human voice or birdsong. For noise monitoring, events occur on a much longer time scale, and a coarser resolution can be

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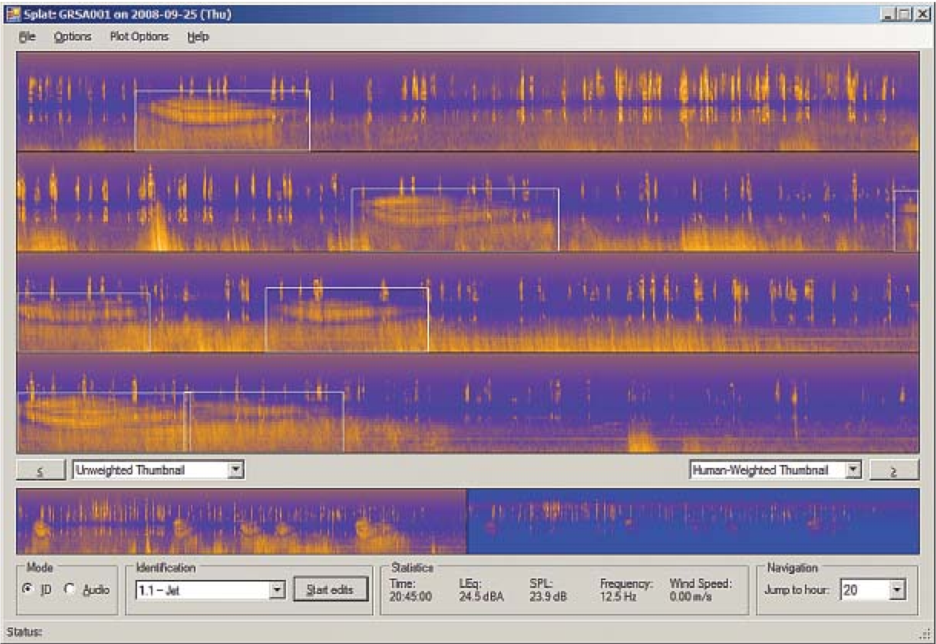

Figure 5. Screen shot of the visual analysis tool developed by the Natural Sounds Program. High-altitude aircraft events have been highlighted. The numerous mid-frequency events are elk bugling.

used. Daily spectrograms do not show nuances of a birdcall, but they do present a "snapshot" of acoustical conditions at that site. Aircraft, vehicles, voices, animal calls, thunder, and other sources are all discernible.

To build on the utility of spectrograms, the Natural Sounds Program developed a visual analysis tool to log events and automatically calculate metrics based on event frequency. A screen shot of the program, called SPLAT (Sound Pressure Level Annotation Tool), is shown in figure 5, with several high-altitude jet events outlined. The continuous audio is also linked to the program, so if the user finds an unknown event, he or she can highlight it and listen to the corresponding audio. Every selected event is logged along with duration, maximum level, and sound exposure level (SEL). Analysis using this tool is anywhere from four to ten times faster than audio subsampling, depending on the complexity of the spectrogram.

Conclusion

The proliferation of tools for audio data collection and analysis offers parks many choices for acoustical monitoring. To navigate these options, parks should identify their objectives and contact the Natural Sounds Program to determine appropriate monitoring plans and equipment. Acoustical monitoring need not be expensive or complicated.

Acoustical monitoring can help protect natural sounds and outstanding conditions for hearing them. In addition, parks can use these methods to count rare or shy species, to track the appearance and spread of endangered species, and to document phenological changes that will accompany climate change. Natural sounds can be startling, haunting, beautiful, and inspirational. They also offer a wealth of ecological information that can advance scientific understanding of park ecosystems and inform park management plans.

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Integrating soundscapes into National Park Service planning

By Vicki McCusker and Kerri Cahill

SOUND ADDS A RICHNESS TO experiencing our national parks that sight alone cannot provide: elk bugling in the cool autumn air of Great Sand Dunes National Park, waterfalls thundering in Yosemite Valley, the quiet hush of Haleakala Crater, muskets and artillery firing at Gettysburg National Military Park. The acoustic component or soundscape of any setting is the audio equivalent of a landscape, viewshed, or watershed and comprises all the sound conditions in a given environment, including human-caused and natural sounds. Acoustic resources that fall under NPS management include wildlife, waterfalls, wind, rain, and historical and cultural sounds.

Natural sounds are increasingly recognized as an important component of resource conditions and visitor opportunities in national parks because, as a growing body of research suggests, human-caused noise can be disruptive to natural ecological processes and visitor experiences. Noise impacts the acoustic environment much as smog affects the visual environment because it reduces the auditory horizon for both visitors and wildlife. In many cases, hearing is the only option for experiencing certain aspects of our environment, such as wildlife that can be heard at much greater distances than they can be seen. However, a healthy soundscape is not limited to the sounds of nature. Human sounds have an appropriate place in the outdoors. Cultural and historical sounds, such as the sounds of the working cattle ranch at Grant-Kohrs Ranch National Historic Site, and the church bell at Mission San Juan, San Antonio Missions National Historical Park, are important components of many national park units.

Despite their importance, soundscapes are often overlooked or impacts to this resource are understated in NPS planning and decision-making processes. For example, rationalizations include that the developed area already has noise impacts so adding more will not make much difference; this is an urban area so soundscapes are not an issue; or the area is so impacted there is no natural soundscape.

Another factor influencing management and policy decisions is that soundscape as a resource is a relatively new topic. As a result, there is a shorter history associated with policy and court decisions. In addition, many of the existing general acoustic research and policy decisions of other federal agencies, such as the Federal Aviation Administration (FAA), have been focused on urban areas and community annoyance, not on areas that are representative of national park units or on issues related to visitor experience. However, recent court decisions have implications for soundscape management. In September 2009, a federal judge issued a preliminary injunction against oil and gas well drilling at Baca National Wildlife Refuge (Colorado) that hinged in part on sound monitoring data collected by the Natural Sounds Program in adjacent Great Sand Dunes National Park (Streater 2009). The plaintiffs maintained that the soundscape at the refuge would be ruined by the noise from oil and gas wells. The judge cited that the refuge had a large expanse of undeveloped land with a significant "sense of place and quiet" (Gable 2009).

Establishing desired conditions and setting indicators and standards for soundscapes in planning documents give soundscape management additional political strength especially when external sources of noise threaten park soundscapes. The general management plan for Great Sand Dunes National Park includes desired conditions for soundscapes. This will be important as the previously mentioned lawsuit moves forward, since it confirms the level of protection for soundscapes that would need to be addressed by the U.S. Fish and Wildlife Service if oil and gas drilling in Baca National Wildlife Refuge is pursued. Another example is contained in FAA guidance (FAA 2007) on supplemental noise analyses for airport improvement

The historical focus in the National Park Service has been on mechanized noise, especially aircraft overflights, or on park-specific noise issues such as snowmobiles, off-road vehicles, and personal watercraft, rather than on a comprehensive approach to soundscape management planning.

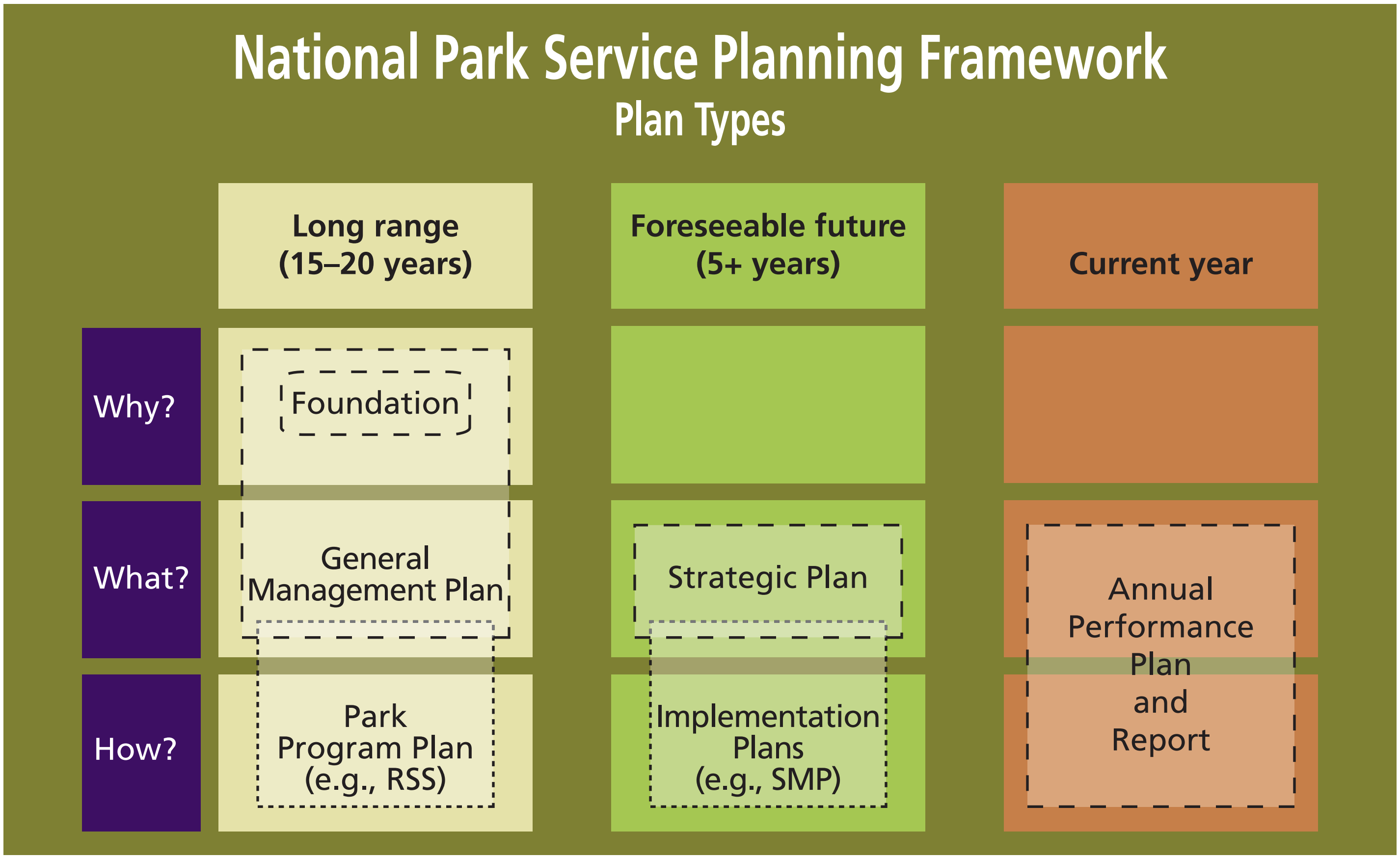

Figure 1. NPS planning framework: Plan types (adapted from NPS 2008).

projects. The guidance directs analysts to review approved park management plans to confirm how the park is managed for visitor use, resource conservation, and wildlife protection in order to identify sensitive locations in the vicinity of the project that may require further analysis.

The historical focus in the National Park Service has been on mechanized noise, especially aircraft overflights, or on park-specific noise issues such as snowmobiles, off-road vehicles, and personal watercraft, rather than on a comprehensive approach to soundscape management planning. Proper management of soundscapes is becoming more complex and challenging as threats to acoustic resources, both internal and external to park boundaries, increase. Planning is an essential step in addressing these threats. This article presents a brief overview of how soundscape management planning fits in the context of the NPS planning framework. It also identifies some of the research/issues that need to be addressed to assist in the development of management strategies and to ensure that park managers and policy makers have sufficient information to preserve, restore, and enhance soundscapes in accordance with *NPS Management Policies* 4.9.

Figure 1 and the supporting discussion illustrate the NPS planning framework and how soundscapes fit into this framework.

Long-range planning

Foundation statements provide the basis for planning and management of a park unit by articulating its core mission. A foundation statement includes identification of a park's purpose, which is the specific reason(s) for its establishment. A park's significance is also identified, which includes statements of why, within a national context, the park's resources and values warrant national park designation. Another aspect of the foundation statement is identifying the resources and values that are "fundamental" to supporting the park's purpose and significance (NPS 2008). Protection of soundscape values is often part of the park's purpose or significance. In these cases, soundscape-related resources and values are also identified as fundamental and may be characterized as exemplifying "serenity," "a contemplative environment," and "natural sound conditions," or promoting "solemn appreciation."

General management plans provide the broadest direction for those resource conditions and visitor experiences that should exist in order to best fulfill the purpose and significance of the park and support its fundamental resources and values (NPS 2008). Importantly, a general management plan should meaningfully describe the qualitative desired conditions for soundscapes, and how those desired conditions may vary by management zone within the park. For example, a recent general management plan included desired conditions for the soundscape in various management zones. Following is an example excerpted from this plan for two park management zones.

Soundscape desired condition for the sensitive resource zone: The natural soundscape is intact in this zone and is an integral part of the visitor experience. Natural sounds are occasionally mixed with sounds from human activity and visitor use. Noise disturbance of wildlife is minimal in this zone.

Soundscape desired condition for the historic immersion zone: Natural sounds are audible and enhance the visitor experience in this zone. Historically appropriate sounds also enhance the experience of this zone. The soundscape is affected by the developed landscape. During times of low visitation, including nighttime and off-peak times, the natural soundscape could predominate, with occasional noise-free intervals.

Park program plans

A resource stewardship strategy (RSS) is one type of program plan in the NPS planning framework and ideally would follow development of a park general management plan. The resource stewardship strategy provides quantitative indicators, target values, and long-term, comprehensive management strategies to achieve and maintain desired natural and cultural resource conditions over time. Indicators, target values, and corresponding management strategies for soundscapes should be included in many park resource stewardship strategies. An example of an indicator and target value from a recent resource stewardship strategy follows.

Indicator: Occurrence of non-natural sounds as expressed by percentage time audible per day.

Target value: Non-natural sounds are audible less than 10% of the day in no more than 25% of the backcountry zone.

Implementation planning

Implementation plans provide direction on the specific actions that will be taken to achieve the desired conditions and comprehensive strategies outlined in the general management plan and program plans, respectively. These include soundscape management plans (SMP) and wilderness or backcountry plans. The implementation plans should contain specific soundscape-related management objectives and actions.

Example of soundscape objectives for a visitor services area:

- Natural sounds are audible and discernible, with common noise intrusions by visitors and park operations. Active intensive management is used to maximize noise-free intervals and limit the intensity and duration of noise intrusions.
- Noise levels that interfere with general conversation rarely[1] occur and are of limited duration except when caused by emergency services (sirens), search-and-rescue operations (search-and-rescue aircraft), and park maintenance operations (road repairs, building maintenance).
- Sound levels that interfere with interpretive programs do not occur except when caused by emergency services and search-and-rescue operations (sirens, search-and-rescue aircraft).
- Sound levels that exceed thresholds for sleep interruption rarely[1] occur during late evening and nighttime hours.

Example of potential soundscape management actions:

- Continue operating the shuttle system and eventually phase out tour buses to reduce noise levels and eliminate the greatest source of park noise.
- Minimize noise generated by park management activities by strictly regulating NPS and concession administrative use of noise-producing machinery, including aircraft and motor vehicles.
- Noise will be a consideration when procuring and using park equipment. Prior to purchase, research will be conducted in regard to the best available technology and the quietest equipment will be identified.

Impact assessment and thresholds

Another important element that supports thoughtful decision making and is common to all types of plans is impact assessment and thresholds for National Environmental Policy Act documents. Impact analyses must take into consideration the context, intensity, and duration of potential impacts (NPS 2001). Impact methodology and thresholds for soundscapes help to assess the potential minor to major

[1] "Rarely" is quantified on a park-by-park basis, but might be less than 5%, for example.

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Table 1. Social science, resource, and management questions for soundscapes research

Social and resource questions	Management questions
What aspects of the natural or historical soundscape are most influential for visitor experience?	What suite of metrics will be most effective and efficient in providing information regarding intensity, context, and duration of noise impacts?
What aspects and combination of human-caused noise (type, frequency, duration, loudness) create the most impact on wildlife, visitor experience, and other park values?	Is there a common set of metrics or indicators for soundscapes, wildlife, and visitor experiences?
How much human-caused noise from specific sources is too much?	Is there a common set of metrics or indicators for different park settings?
What are visitors' expectations of soundscapes in different park environments, and how do we best evaluate consistency with these expectations? How do these expectations vary by type of visitor?	Which management strategies are most effective and efficient at minimizing human-caused impacts to the soundscape?
Specifically, what does "solitude" mean from a soundscapes perspective?	

impacts on soundscapes and related values resulting from management actions being considered in a park plan. Impact criteria and thresholds are park-specific and may be qualitative or quantitative depending on the type of plan. Impact thresholds in a general management plan would be qualitative because of the broad direction provided in the plan. Thresholds in an implementation plan could be quantitative and based upon metrics depending on the type of analysis being used, such as computer modeling of potential noise impacts from a specific source such as aircraft or motorized vehicles.

To protect and restore important soundscape values in national parks, it is important that the National Park Service continue to progress toward comprehensive planning for soundscapes. This means that a careful examination of soundscapes should be addressed at all levels of planning, as we have outlined, and with enough detail and substance to provide meaningful management direction for the future. If the decision is made to dismiss soundscapes during a planning process, dismissal language that articulates the rationale for dismissal and, where appropriate, that highlights known issues can also support NPS efforts in working with other agencies regarding noise issues. The Governors Island General Management Plan (2009) dismissed soundscapes but did so in a way that will support protection of soundscapes during the air tour management planning process currently under way (see sidebar).

Challenges and future research

In order to address the challenges of soundscape management and to better integrate the topic of soundscapes into the planning framework, more information and research are needed. Recent and emerging techniques in monitoring and use of additional metrics and visitor surveys support an increase in informed decision making regarding soundscapes. However, important questions remain that should be the focus of future research to help park staff better understand, evaluate, and plan for the future of soundscapes in the national parks. Table 1 lists some of these questions.

How to get help with soundscape planning and impact assessment

The Natural Sounds Program can provide specialized technical assistance to parks, regional offices, and the Denver Service Center to integrate natural resource information into park foundation documents, general management plans, resource

Excerpt from Governors Island General Management Plan

Parts of Governors Island are places to enjoy fewer man-made sounds compared to the highly urban environments surrounding the island. Even though Governors Island National Monument was not established as a reprieve from urban life, many visitors remark that the island is an oasis from the noise, fumes, and general bustle of the surrounding city. Visitors can hear the water against the seawalls and the wind through the trees. At the writing of this GMP, the most intrusive and disruptive element is noise from helicopters which fly directly overhead and sometimes at quite low altitudes. The noise they generate often disrupts public programs and tours. The NPS, in cooperation with its on-island partners, will seek to have formal memoranda of agreement with the Federal Aviation Administration (FAA), the Eastern Region Helicopter Council, city and state agencies, as well as private operators, to control helicopter noise. (Chapter 1, page 26, Governors Island National Monument Final General Management Plan and environmental impact statement)

A growing body of information and experience now exists to support comprehensive soundscape management planning.

stewardship strategies, and park-specific soundscape management plans. For example the Natural Sounds Program has participated in user-capacity workshops for Golden Gate National Recreation Area and also workshops for the City of Rocks National Reserve General Management Plan. There are several ways parks can get assistance but timing of requests is crucial:

- Technical assistance request at the start of or early in a planning process through the new Solution for Technical Assistance Requests (STAR) at http://nrpcstar, or an informal request made directly to the Natural Sounds Program.
- Natural Sounds Program review of internal draft general management plans. Note that the ability of the Natural Sounds Program to assist is limited at later stages in a planning process, particularly if monitoring is requested.
- New soundscapes forum on InsideNPS, http://inside.nps.gov/forum/categories.cfm?catid=46, for planners, scientists, and interpretation staff to discuss all aspects of soundscapes, including management policy, field monitoring, and education and outreach.

Conclusion

Soundscapes are a vital, sensitive cultural and ecosystem component of national park units. Therefore, consideration of soundscapes through all phases of the planning process—from the foundation document to implementation plans—confirms the level of protection that the National Park Service accords soundscapes. It is key to working with other entities or agencies, such as the Federal Aviation Administration, whose policies or interests regarding noise impacts are different and often less protective than NPS policies and mandates. Also, the planning process helps educate future managers and the public about the importance of and resource protection needs associated with soundscapes.

The Natural Sounds Program has partnered with social scientists to conduct soundscape surveys in Muir Woods National Monument (Golden Gate National Recreation Area General Management Plan with Denver Service Center), Rocky Mountain National Park (transportation plan), and Haleakala and Hawai'i Volcanoes national parks (air tour management plans) to inform planning processes. The information gained from these research efforts is being used in current planning processes to support development of desired conditions and quantitative indicators and standards. Although more research is required to answer our questions, a growing body of information and experience now exists to support comprehensive soundscape management planning. The NPS Natural Sounds Program will continue to partner with social science and wildlife researchers and acoustic experts in the federal, academic, and private sectors to investigate these key questions and provide guidance for incorporating science into soundscape planning and management decisions.

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Case Studies

NPS PHOTO/JARED WITHERS

Soundscape monitoring and an overflights advisory council:

Informing real-time management decisions at Denali National Park and Preserve

By Jared Withers and Guy Adema

DENALI NATIONAL PARK AND PRESERVE is a six million acre (2.4 million ha) land in central Alaska, most of which is either designated as or suitable for wilderness. It features North America's highest mountain, 20,320-foot tall Mount McKinley and also includes countless other spectacular mountains and many large glaciers. Denali's ecosystems span over 17,000 vertical feet (5,185 m) and encompass a complete set of subarctic ecosystems that include boreal lowlands, expansive subalpine tundra, and alpine and mountain areas. The park was established as Mount McKinley National Park on 26 February 1917. The original park was designated a wilderness area and incorporated into Denali National Park and Preserve in 1980. The park was designated an international biosphere reserve in 1976.

In order to properly manage this vast wilderness, the park completed a major amendment to its general management plan in 2006, a comprehensive backcountry management plan and environmental impact statement (BCMP). The backcountry management plan is the result of a public process that took eight years and included specific management goals for Denali's variety of backcountry lands: designated wilderness, suitable wilderness,

A National Park Service high-elevation rescue helicopter flies over an automated sound station on Mount McKinley's West Buttress climbing route, elevation 10,500 feet.

national preserve, national park, and other undeveloped park lands. The plan created management zones to accommodate a range of backcountry users accessing the park in a variety of ways, such as day hikers, backpackers, mountain climbers, snow machiners, and hunters. Soundscape is a critical resource specifically addressed in the backcountry management plan. Three acoustic indicators were established with standards defined for each of the

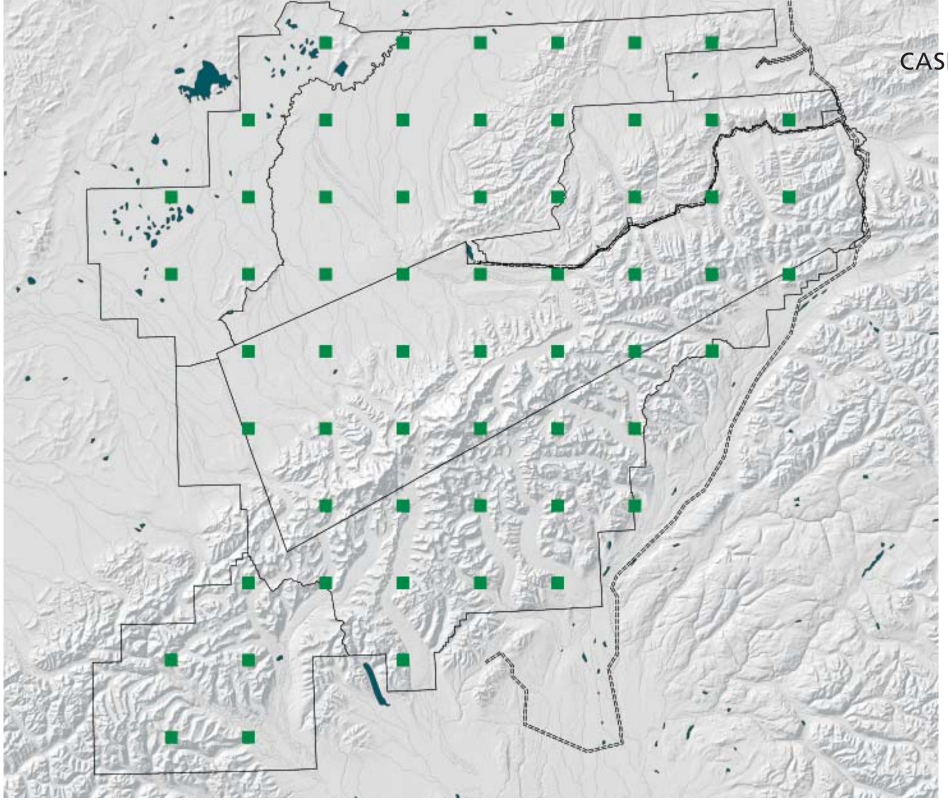

Figure 1. This map illustrates the grid locations to be sampled for a parkwide inventory of natural and human-made sounds.

various management zones created by the plan.

1. Percentage of any hour when motorized noise is audible
2. Number of motorized noise intrusions per day that exceed natural ambient sound
3. Maximum motorized noise level

Denali initiated soundscape measurements in 2000 in order to establish acoustic standards for the forthcoming backcountry management plan and in response to Director's Order 47, which articulates operation policies for protection, maintenance, and restoration of the natural soundscape resource. Upon completion of the plan, this pilot program developed into a protocol designed systematically to sample the soundscape of the entire park at a landscape scale, with the objectives of inventorying current conditions, long-term trend analysis, and informing park management's implementation of the plan.

To achieve these goals, automated monitoring stations are temporarily deployed to six grid locations per year, measuring all 60 points over a 10-year period (fig. 1). Two additional non-grid sites are monitored each year at locations where data necessary for management on a shorter-term return cycle are required or where focused local data are desired. Remote stations collect interval audio recordings and spectral sound pressure level (i.e., loudness) data for at least one month per site during the operational season (May–September). The interval recordings are a five second audio clip recorded every five minutes, and spectral data are calibrated one-third-octave band sound pressure levels sampled once a second. Winter conditions are also monitored through an alternate scheme that aims to track acoustic conditions in areas of traditional winter use.

The methods and analyses are designed to inform progress directly toward the standards identified in the backcountry management plan, as well as to provide an accurate profile of the natural soundscape at each sample location. For example, data from near the terminus of Tokositna Glacier demonstrate observed conditions relative to BCMP indicators and standards and are shown in figs. 2, 3, and 4. These data reveal that there is significant overflight activity at this location, but it is largely within the desired future conditions

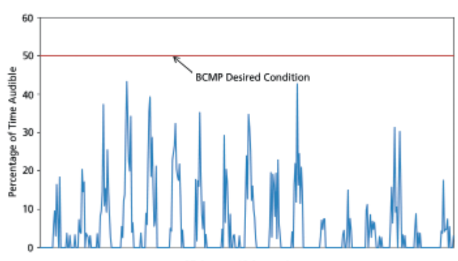

Figure 2. The graph shows the percentage of time motorized aircraft sound is audible, by hour, at the Tokositna Glacier in 2008.

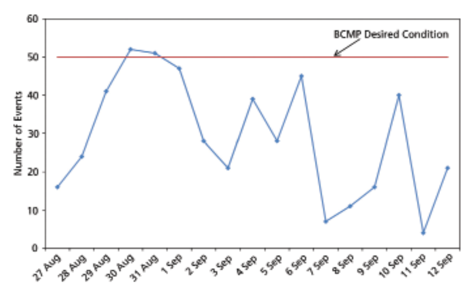

Figure 3. The graph shows the number of aircraft overflight events per day at the Tokositna Glacier in 2008.

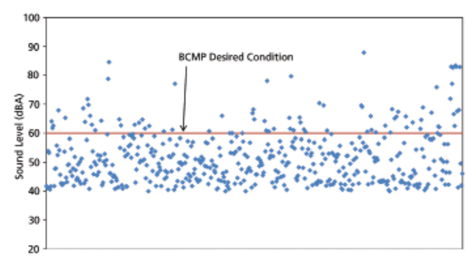

Figure 4. The graph shows maximum A-weighted sound pressure levels of each aircraft overflight at the Tokositna Glacier during the 2008 measurement period. A-weighting is a correction curve that attenuates certain frequency bands in the same way the human ear does, yielding sound pressure levels that are representative of what a human would perceive.

Case Studies

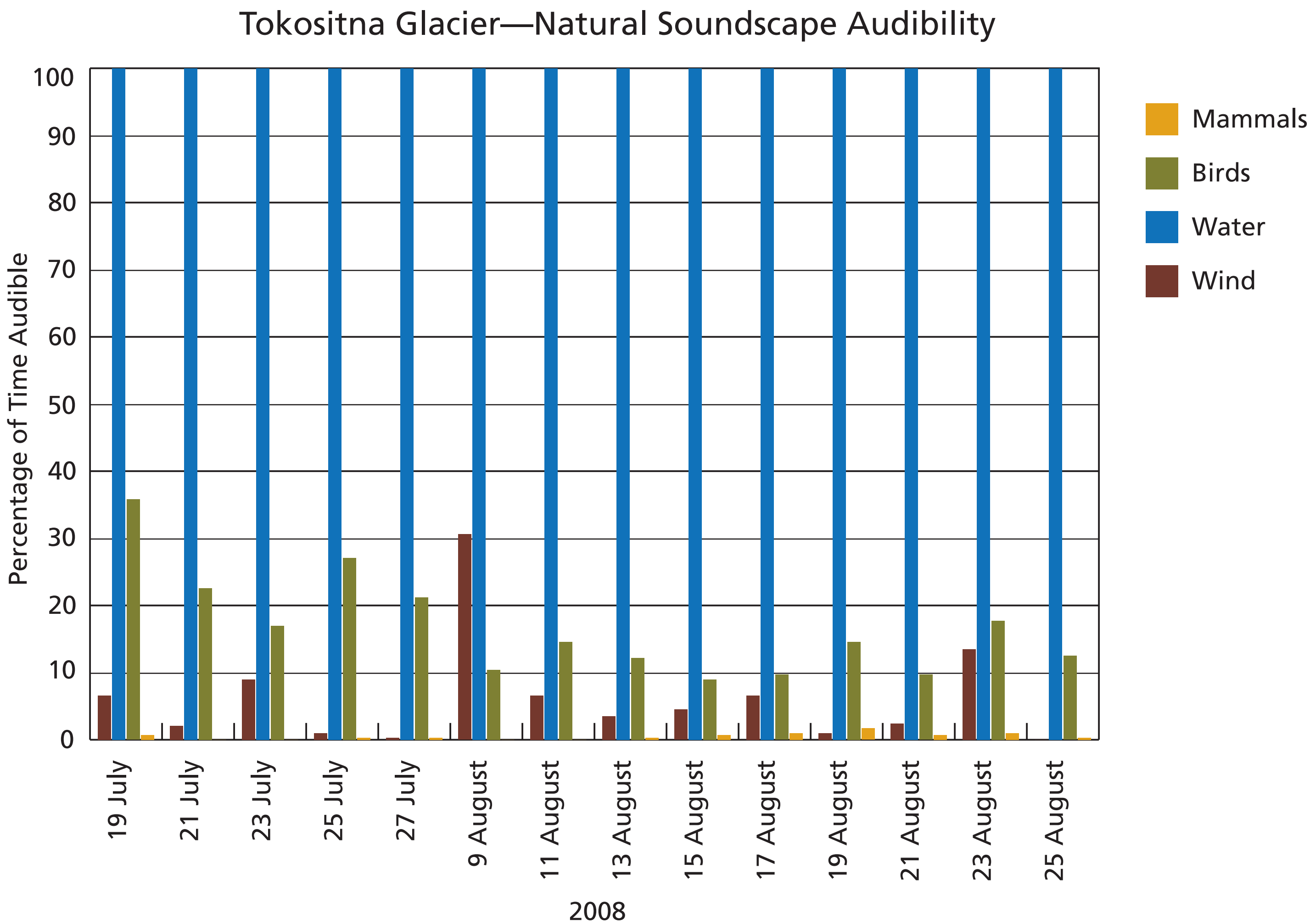

Figure 5. The graph shows the percentage of time a range of natural sounds measured at the Tokositna Glacier in 2008 were audible.

identified for this zone. Figure 5 shows the distribution of the natural sounds at the same location. This site is located at a glacial terminus, and the sound of flowing water is audible 100% of the time; birdcalls are often audible and mammal sounds are occasionally heard.

In addition to the inventory and monitoring of the soundscape, the backcountry management plan calls for the establishment of a formal Aircraft Overflights Advisory Council. Although Alaska is exempt from the National Parks Air Tour Management Act of 2000 and does not have an air tour management plan requirement, the Aircraft Overflights Advisory Council is chartered under the Federal Advisory Committee Act and has a diverse membership representing interests of the Federal Aviation Administration, State of Alaska, mountaineers, backcountry users, general aviation, local businesses, private property owners, air taxi operators, sightseeing flight operators, local and national environmental groups, and military flight operations. The advisory council's task is to advise the Secretary of the Interior about voluntary measures to reduce the impacts of overflight noise on the natural soundscape and increase safety for passengers, pilots, mountaineers, and other backcountry users. These measures would help the park achieve the desired future resource conditions identified in the backcountry management plan.

Since the creation of the Aircraft Overflights Advisory Council, Denali's sound program has worked intensively to collect and interpret acoustic data so that the council can make recommendations based on objective and accurate measurements of soundscape conditions. Data have been synthesized to highlight areas of the park that both meet and exceed desired future conditions. Figure 6 shows which areas of the park meet or exceed the BCMP "number of events per day" desired future condition based on field measurements to date. In this instance, the data indicate that the low disturbance zone in the central area of the park, federally designated as wilderness, is most in need of attention to meet desired conditions.

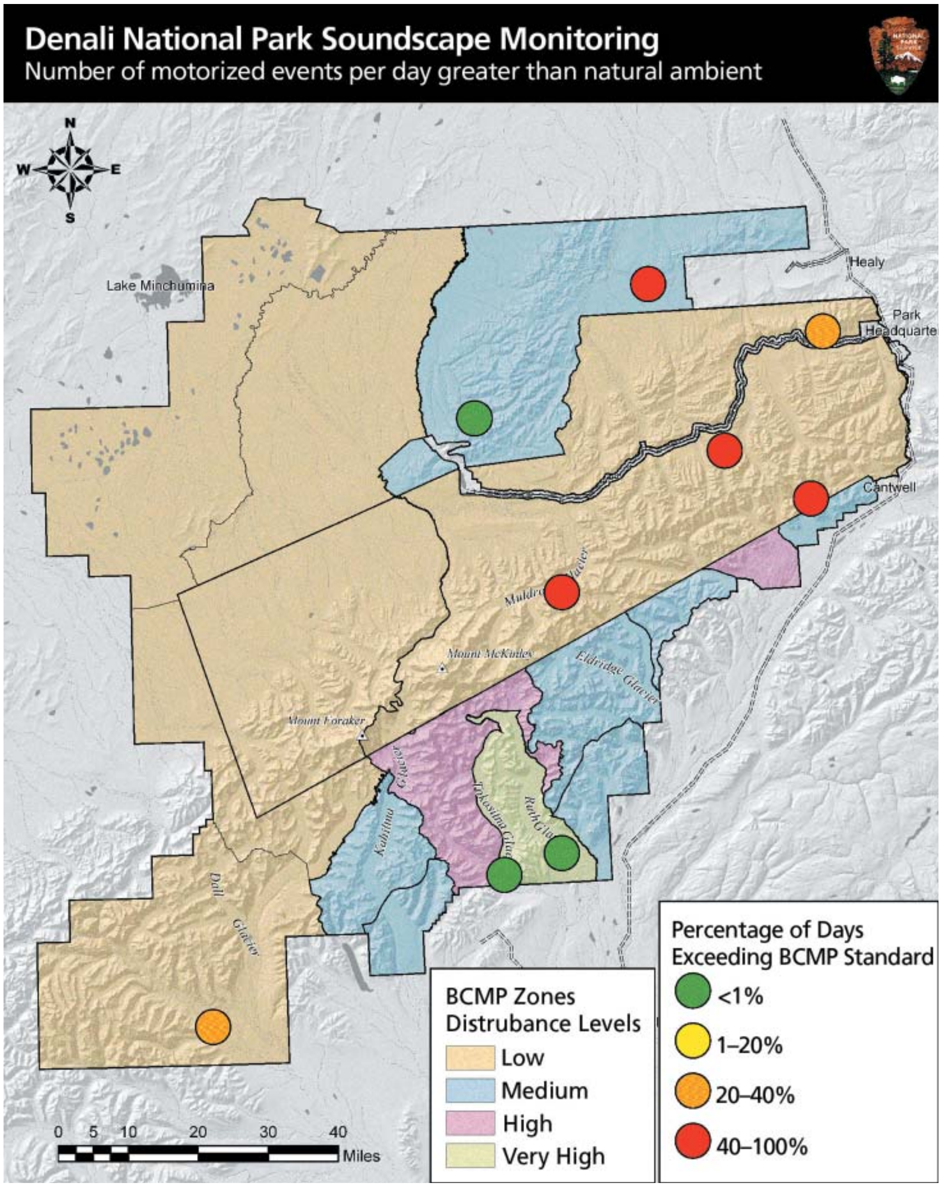

Figure 6. This map illustrates the percentage of samples exceeding the backcountry management plan "number of events per day" desired future condition at nine locations within Denali.

The central area of the park, federally designated as wilderness, is most in need of attention to meet desired conditions.

The Aircraft Overflights Advisory Council has worked closely with the park soundscape program to understand the acoustic environment, monitoring results, data strengths and limitations, and established standards. Through listening sessions, annual data review, and technical presentations, the members not only have a working knowledge of soundscape management but also use monitoring results to seek options for improving Denali's backcountry experience for visitors. In 2010 , NPS scientists will be working with the Aircraft Overflights Advisory Council and local air touring companies to test and evaluate the effects of actions aviators could take to reduce impact on a popular wilderness day-hiking area, and at the West Buttress climbing route on Mount McKinley.

This cooperative effort is moving Denali National Park and Preserve toward its goal of reducing the noise impact of aircraft overflights to meet management standards and improve visitor safety through expanded communication. The close interaction of a holistic soundscape montoring program and the Aircraft Overflights Advisory Council is proving to be a constructive solution to achieve Denali National Park's management objectives and could serve as a model for other Alaskan parks.

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Soundscape management at Grand Canyon National Park

NPS PHOTO/SARAH FALZARANO

Acoustic Technician Laura Levy samples sounds from Colorado River rapids.

By Jane Rodgers

IN FEBRUARY 1919, THE FIRST AIR TOUR over the Grand Canyon was recorded; that fall the area was officially designated as Grand Canyon National Park. Fifty-six years later, the 1975 Grand Canyon National Park Enlargement Act established that where impacts from aviation occur, natural quiet should be protected as both a resource and a value in the park. Following the National Parks Overflights Act of 1987, the Federal Aviation Administration established a special flight rules area for the park. In an effort to restore natural quiet at Grand Canyon and to improve aviation safety, flights were restricted below 14,500 feet, flight-free zones were established, and special routes for commercial sightseeing tours were created. After another 20 years of interim regulations, congressional interest, departmental reports, negotiations and consultation, and the establishment of a National Park Service-Federal Aviation Administration Grand Canyon Working Group, Grand Canyon National Park is finally on the verge of completing an environmental impact statement to achieve substantial restoration of natural quiet at the park.

So where's the science? In 2003, the park's Science and Resources Management Program recognized the critical need to establish a soundscape program to collect and analyze local acoustic data. The Grand Canyon Soundscape Program has since played an active support role in park planning to better steward park soundscapes. In support of overflights planning, Grand Canyon staff recorded 12 months of continuous audio data and measured decibel levels under air tour corridors (see photo, opposite, at right). These data allowed park managers to determine natural sound levels for winter and summer seasons in four vegetation zones. Because *NPS Management Policies* states that the natural ambient sound level is the baseline condition or standard for determining impacts to soundscapes, these data provide park managers with essential information needed for soundscape planning in the park. Data were used to compare noise models, assess developed and transitional area soundscapes, and create visual spectrograms for aircraft audibility analysis (see article, page 48). In order to assess impacts to the threatened Mexican spotted

The 1975 Grand Canyon National Park Enlargement Act established that … natural quiet should be protected as both a resource and a value in the park.

owl, acoustic data were collected adjacent to breeding sites; data are currently being analyzed using sound analysis software such as Raven (http://www.birds.cornell.edu/brp/raven/RavenOverview.html) to look for correlations between aircraft noise and the disturbance of birds.

In addition to overflights monitoring and management, the park has been interested in a variety of other planning and stewardship activities relating to soundscapes. Activities included collection and analysis of acoustic data from river rapids (see photo, opposite), fire-fighting equipment (see photo, below), and popular visitor use areas. Recently, a sound system was deployed at Tusayan Ruins, located near Desert View, to quantify noise from air tours interfering with ranger programs (using the U.S. Environmental Protection Agency criterion for speech interference for interpretive programs). In 2008 and 2009, soundscape staff collaborated with the Grand Canyon Youth program to develop a soundscape-themed science project for visually impaired teenagers (see article, page 50). Outdoor recreation planning staff also used acoustic data to determine if helicopters exchanging river trip passengers are complying with Colorado River Management Plan guidelines. Finally, in an effort to support our neighboring parks, Grand Canyon National Park staff established 2007 baseline sound levels at Walnut Canyon National Monument prior to runway expansion at Flagstaff's Pulliam Airport.

While the current focus of the park's soundscape work relates to overflights planning, park staff hopes to broaden the program across all cultural and natural soundscape issues. Future efforts will include the development of a parkwide soundscape management plan and implementation of the overflights environmental impact statement.

Further information

For more information and copies of all park reports and publications, please visit our Web site at http://www.nps.gov/grca/naturescience/soundscape.htm.

About the author

__Jane Rodgers__ is the Science and Resources Management deputy chief for socio-cultural resources at Grand Canyon National Park and coordinates work on soundscape issues on a part-time basis. (The park plans to hire a full-time acoustic technician to monitor the soundscape following completion of the overflights environmental impact statement.) Rodgers can be reached at 928- 606-5793 and by e-mail at jane_rodgers@nps.gov.

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NPS PHOTO/SARAH FALZARANO

NPS PHOTO

(Above) Sampling sounds from firefighting equipment. (Right) This acoustic monitoring station records aircraft overflight noise occurring in the special flight rules area of Grand Canyon National Park.

Case Studies

Tools of the trade: An example of using spectrograms to count fixed-wing aircraft

By Laura Levy and Sarah Falzarano

SPECTROGRAMS ARE A USEFUL TOOL that many National Park Service (NPS) soundscape scientists employ to examine decibel data. For example, they translate decibel data collected in daily or hourly units into a visual format, enabling a quick scan of hundreds of hours' worth of data for the occurrence of natural and human-caused sound sources at a particular site. Each sound source has its own signature based on frequencies, loudness, and timing, making it easy to identify. Spectrograms are created by converting 1-second decibel and one-third-octave band data into a visual format using statistical analysis software, called "R," and an "R" script written by the NPS Natural Sounds Program.

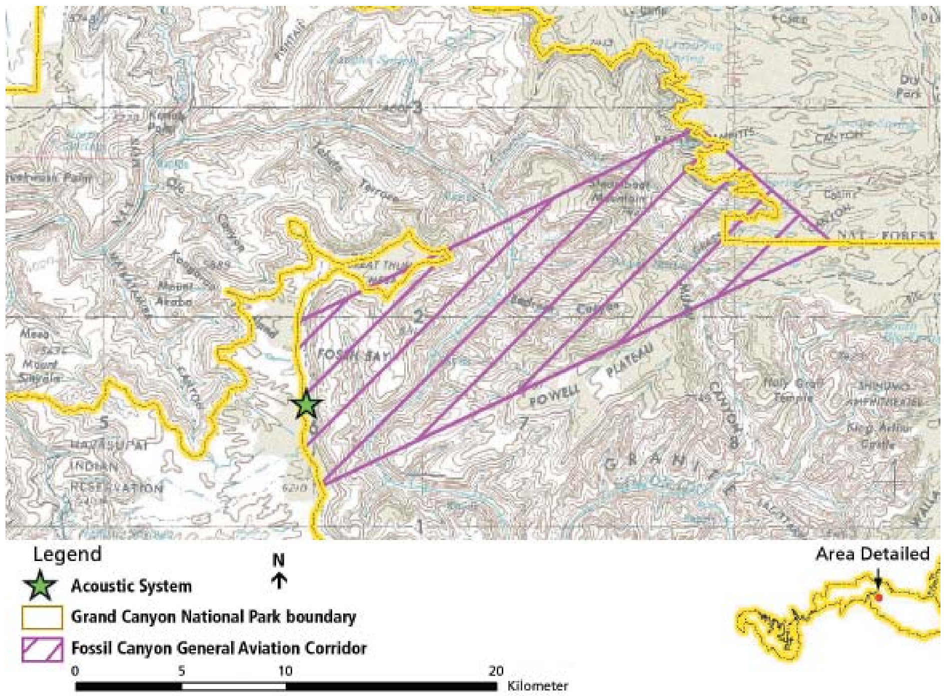

Figure 1. The map depicts the Fossil Canyon general aviation corridor in Grand Canyon National Park. The acoustic data collection system location is identified by the green star, located approximately 40 miles (64 km) from the South Rim Village via dirt roads.

Recently the Soundscape Program at Grand Canyon National Park was tasked with determining the number of fixed-wing aircraft using the Fossil Canyon general aviation corridor over the park (Levy and Falzarano 2007). This corridor is located in a remote part of the park (fig. 1), making an on-site, real-time tally of fixed-wing aircraft unrealistic. Park staff placed an acoustic system in the corridor for one year starting 1 November 2006 (fig. 2). The acoustic system consisted of a Panasonic CF-18 Toughbook laptop, an ANSI type 1 Larson-Davis sound-level meter (model 824), a microphone (GRAS 40AE), and a preamplifier (Larson-Davis 902). Twelve-volt, lead-acid batteries powered the system, recharged by two 80-watt arrays of solar panels. Total system cost was approximately $14,000. Though this may seem cost-prohibitive for some parks, it is important to keep in mind that equipment can be shared between parks, and the data collected could serve a multitude of purposes. Twenty-four-hour spectrograms were created for 365 days of decibel data, enabling program staff to count fixed-wing plane signatures. Spectrograms provided timely, quality information and obviated the need to listen to hundreds of hours of sampled recordings. Instead, park staff were able to identify fixed-wing aircraft on the spectrograms by their "staircase" or "corkscrew" signature shape (fig. 3), which were confirmed by listening to corresponding recordings.

Results show that a total of 1,504 fixed-wing aircraft used the corridor over 10 months with an average of 5 fixed-wing planes per day. Two months of data (August and September) were lost due to equipment failure when an elk knocked over the microphone, which filled with water. Beyond tallying aircraft, park staff used the spectrograms to ensure quality control of collected data, to monitor times of helicopter flights, and to quickly locate recordings of interesting wildlife sounds such as coyotes howling and elk bugling. Spectrograms can be generated in a matter of minutes and display 24 hours of data at a time. Therefore, spectrograms can quickly show data gaps (system failure) or noise interference (e.g., field staff checking the system on site). The park Soundscape Program continues to use spectrograms in a variety of ways to aid management, and this tool has great potential for park interpretive and education programs.

Figure 2. Laura Levy checks the acoustic monitoring station for the Fossil Canyon general aviation corridor at Grand Canyon National Park. The solar arrays measure approximately 24 x 30 inches and 42 x 30 inches.

NPS PHOTO/SARAH FALZARANO

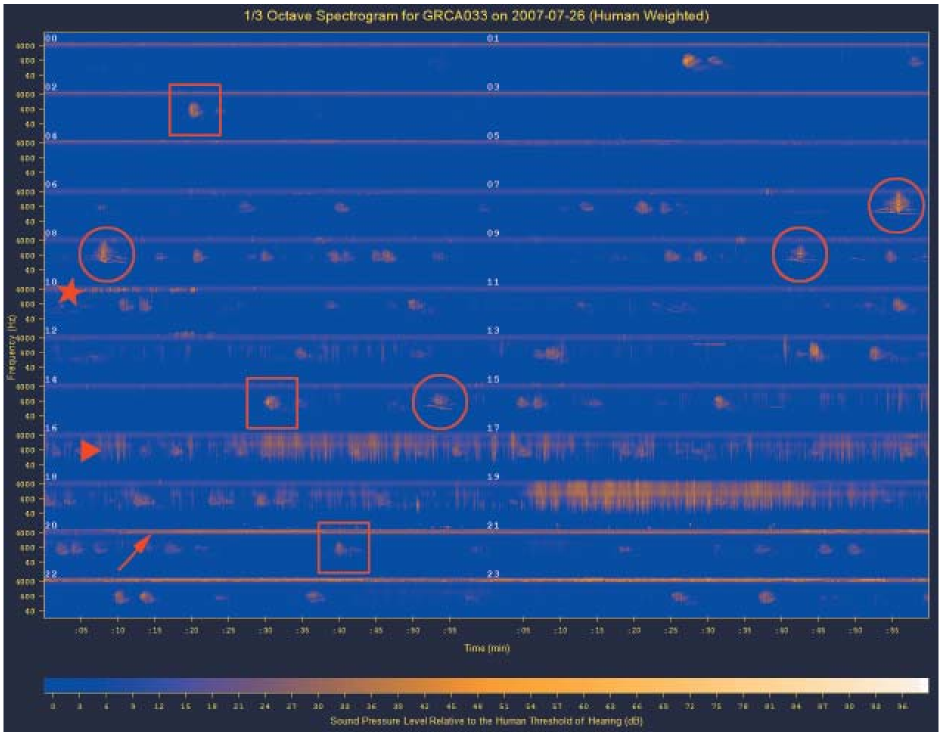

Figure 3. This spectrogram shows sound pressure level (i.e., volume) data for the Fossil Canyon general aviation corridor on 26 July 2007. White numbers (00 to 23 hours) signify time of day, frequency is indicated on the Y axis in Herz, and decibel levels are indicated by color (dark blue through yellow) relative to the human threshold of hearing (0–100 dB). Propeller planes are circled, some but not all jets are marked by rectangles, arrows indicate insects, the star illustrates birds, and the triangle points to wind signatures.

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Case Studies

PHOTO COURTESY OF GRAND CANYON YOUTH

Visually impaired students help collect acoustic data in Grand Canyon National Park

Students, staff, and crew of the Leading the Way program commemorate their trip down the Colorado River with a photo. The participants logged natural and human-related sounds at seven locations in Grand Canyon National Park.

By Laura Levy and Sarah Falzarano

DURING SUMMER 2008, 12 VISUALLY impaired students along with sighted teenagers and guides embarked on a Colorado River trip through Grand Canyon National Park that was the first of its kind. They were participants in a program called "Leading the Way," a partnership between two nonprofits, Grand Canyon Youth (GCY) and Global Explorers, and two commercial outfitters, Canyon Explorations and Arizona Raft Adventures. Grand Canyon Youth provides experiential education along the rivers and canyons of the desert Southwest. The program requires students to participate in a service project as part of their field experience to encourage resource stewardship. Past projects have involved removing invasive plants and photographing beaches along the Colorado River for a campsite atlas. However, given that hearing is an especially important sense for many in this group, a sound-oriented project was a natural choice. Additionally, this project encourages science education in a national park setting through the involvement of the students in collecting acoustic data for the Grand Canyon National Park Soundscape Program.

Methodology

At 1.2 million acres (0.5 million ha), the sheer size of the national park makes it a challenge for staff of the Grand Canyon National Park Soundscape Program to collect acoustic data across this incredibly diverse landscape. The Leading the Way trip provided a special opportunity to gather preliminary data to help characterize the river soundscape, assist with managing river recreation, and provide input into future draft backcountry and wilderness management plans. Seven locations were monitored along the Colorado River for 15 minutes each. Sites were selected from a list provided by the Soundscape Program or opportunistically as weather and river activities permitted. The list was generated based on the need to collect additional acoustic information from river locations under air tour corridors or, in contrast, from areas suspected to be relatively devoid of air tour noise.

Prior to the GCY work, the park had very little river-based acoustic data. "Observer logging," as the activity is called, is usually conducted for an hour, but weather and time constraints limited the length of these survey sessions. The students were grouped into pairs of visually impaired and sighted individuals. Using a system of hand signals (to eliminate human voice noise), visually impaired students relayed information to their sighted partner about what he or she was hearing and for how long. The sighted student would then interpret the hand signals and document them on a log sheet, noting the time indicated by a watch. At least three pairs of GCY students simultaneously surveyed sounds at each sampling location. At several sites, one or two sighted adults also participated in the survey. The group used a Larson-Davis model 831 sound-level meter to collect 1-second sound pressure levels over a 15-minute period, measured in decibels (dB[A]). They did not make digital sound recordings.

Results and discussion

The group reported hearing many natural sounds, including the river, thunder, wind, insects, and birds. Aircraft that included propeller planes, helicopters, and high-altitude jets were the most common human-caused sounds detected. Interestingly, no motorized rafts were noted during the sessions, perhaps because most of the logging occurred in the late afternoon or early evening when most boats are already parked in camp.

Soundscape Program staff later calculated the minimum, maximum, and median sound levels from the 1-second decibel data. Six of seven sites had median sound levels 2 to 5 dB(A) above minimum sound levels, indicating that sound levels were close to minimum levels for most of the measurement period. Median sound levels at the sites ranged from 49 to 67 dB(A), which are normal near the Colorado River (Falzarano and Levy 2007).

This project encourages science education in a national park setting.

Conclusion and future plans

Overall, this pilot program was a success. Students collected sound data in areas of the park that otherwise require extensive staff time, money, and resources to reach. However, the short duration (15 minutes) of logging offers only a glimpse of the sites' soundscapes. The Soundscape Program, therefore, considers these as pilot data sets, with additional data and locations to be added in the near future. Data collected in 2008 and 2009 will help determine where to conduct more extensive surveys in the future, involving longer durations, and with the addition of digital recordings.

The experience was a good one for the students, who learned about threats to natural soundscapes and the challenges of soundscape management. They were enthusiastic about the project and noted that the experience led them to listen more carefully to their surroundings and notice the natural sounds and the intrusion of human-caused sounds. Students also noted how loud the cicadas were, something they might not have appreciated before.

After the pilot program in 2008, the park decided to conduct more extensive observer logging training with students before any future river trips and to build in longer daily sampling time. In 2009, Grand Canyon Youth, Global Explorers, and Grand Canyon National Park hosted another group of visually impaired and sighted students on a river trip, and it was again a big success. Better training allowed students to begin collecting data immediately and improved the overall workflow and productivity. The staff of the Soundscape Program is excited about this new partnership and looks forward to working with Grand Canyon Youth as we create more stewards of our natural soundscapes.

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About the authors

Laura Levy *and* ***Sarah Falzarano*** *were formerly with the Soundscape Program at Grand Canyon National Park. Laura is now a graduate student at Dartmouth College in the Earth Science Department studying past glacier fluctuations in Greenland; Sarah is with the Army Corps of Engineers in Hawaii. Correspondence can be directed to Jane Rodgers (jane_rodgers@nps.gov).*

Case Studies

Protecting the acoustic conditions at Great Sand Dunes National Park and Preserve

By Frank Turina

IN A DECISION THAT HIGHLIGHTS THE importance of scientific data and analyses in the protection of park resources and values, a federal judge in Colorado indefinitely blocked any drilling in a wildlife refuge next to Great Sand Dunes National Park and Preserve. Given the potential consequences of the judge's ruling, the value of accurate and reliable information supporting the decision cannot be overstated.

U.S. District Court Judge Walker Miller granted a preliminary injunction, ruling that local environmental groups presented adequate evidence that oil and gas drilling would cause irreparable injury to Colorado's Baca National Wildlife Refuge. The decision blocks drilling while the lawsuit moves through the courts.

In his ruling, Judge Miller noted that the refuge contains wetlands, habitat for a variety of wildlife and fish, and a "large expanse of undeveloped land with a significant sense of place and quiet." This statement was based in part on data collected by the Natural Sounds Program at Great Sand Dunes National Park in an area near the proposed drilling sites.

At the request of park managers, the Natural Sounds Program deployed an acoustic monitoring system in the park close to the Baca National Wildlife Refuge from 24 September to 10 October 2008 to assess potential effects from proposed oil and gas development on U.S. Fish and Wildlife Service land adjacent to the park (see the site photo on page 34). Equipment was used to characterize the existing ambient sound levels and calculate natural ambient sound levels.

Table 1. Sound pressure levels at Great Sand Dunes National Park

	Existing Ambient (L_{50})		Natural Ambient (L_{nat})	
Year	Day 08:00-19:00	Night 20:00-07:00	Day 08:00-19:00	Night 20:00-07:00
2008 data	20.5	15.0	17.3	14.7
2009 data**	22.3	11.0	17.0*	8.7*

*Levels are estimated using the L90 exceedence level.
**Low noise microphone.

This monitoring led to the discovery that the acoustical environment in Great Sand Dunes National Park and Preserve ranks as one of the quietest ever monitored by the Natural Sounds Program. The levels recorded during 2008 were extremely low and likely represented the technical limits of the data collection systems used, rather than actual sound pressure levels present at the site. In order to more accurately capture actual acoustic conditions in the park, the Natural Sounds Program returned to the park in 2009 to deploy a highly sensitive, low-noise microphone as sensitive as the human ear at a location known as Alpine Camp. The table shares the existing and natural ambient sound levels at the park from the 2008 and 2009 data.

Preliminary analyses of the low-noise microphone data indicate a nighttime existing ambient sound level of 11 dB(A) and an estimated nighttime natural ambient level of 8.7 dB(A). To put theses levels into perspective, consider that the sound of human breathing at a distance of 3 meters (9.8 ft) is approximately 10 dB(A). Previously, the lowest sound level in a national park (10 dB[A]) was recorded in the volcanic crater at Haleakala National Park, Hawaii.

This monitoring effort was instrumental in describing the acoustic environment of the area and will provide valuable information that can be used to help mitigate potential adverse effects from the proposed energy development. The Natural Sounds Program looks forward to continuing to provide important scientific data and support to help parks characterize and mitigate potential acoustic impacts to park resources from energy development and other activities throughout the National Park System.

About the author

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NPS/KATY WARNER

Generator noise along the U.S.-Mexico border

By Jeff Selleck

OVER THE LAST DECADE THE UNITED States has emphasized the importance of securing its borders. The Secure Border Initiative (SBI) has provided for an increase in the number of Border Patrol agents and construction of border infrastructure such as pedestrian fences. The most recent addition to this infrastructure is surveillance towers that can detect, classify, and track human activity along the border. The Department of Homeland Security is planning for the construction of a network of these towers in and around Organ Pipe Cactus National Monument, Arizona, with the potential for additional towers at or near other national park units in the future.

The National Park Service is concerned about the impacts that construction, maintenance, and operation of the towers may have on natural and cultural resources, including the wilderness character of Organ Pipe Cactus National Monument and Sonoran pronghorn antelope, a federally designated endangered species that is sensitive to noise. The primary source of power for many of the planned surveillance towers will be gas-powered generators, which have been recorded at 70 dB(A) from a distance of 4 meters (13 ft). In anticipation of this project, the National Park Service documented the condition of the existing soundscape in April 2009—before construction—when staff from the Natural Sounds Program monitored ambient sound levels at several proposed tower sites and at an existing surveillance tower at an off-site location.

The results from the monitoring effort were shared with park staff in November 2009 and included an inventory of sounds recorded at each site along with their loudness, frequency, and duration. Not surprisingly, these data revealed that the sites were already impacted, to varying degrees, by border surveillance activities. National monument and Natural Sounds Program staff used this information in conference with the Department of Homeland Security to try to reduce the noise footprint of the generators. Additionally, once the towers are constructed, national monument staff will engage in long-term sound monitoring in order to document and mitigate impacts to the greatest extent possible, for the protection of wilderness values and sensitive Sonoran pronghorn.

About the author

__Jeff Selleck__ is the editor of this publication.

Airport expansion adjacent to San Antonio Missions

Mission San Juan at San Antonio Missions National Historical Park, Texas, is situated approximately one-third mile from the end of the Stinson Municipal Airport runway. The noise from aircraft passing overhead shortly after takeoff is a concern to park managers seeking to preserve the contemplative atmosphere in which visitors can enjoy the mission and its grounds. In 2007, the airport applied to the Texas Department of Transportation to lengthen the runway to 5,000 feet and update the terminal to accommodate greater general aviation use. The airport provides relief to the commercial airport in San Antonio and is economically important for the city. The National Park Service opposed the proposed expansion, noting that it would constitute a "constructive use" of the park by increasing noise encroachment, vibration, and the risk of aircraft accidents. The Texas Department of Transportation approved the request, and expansion of the runway and airport are now under way. In May 2008, Natural Sounds Program staff sampled the sound environment at the mission, establishing a baseline for comparison of changes in noise after the runway becomes operational in 2010.

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Research Reports

A program of research to support management of visitor-caused noise at Muir Woods National Monument

By Robert Manning, Peter Newman, Kurt Fristrup, Dave Stack, and Ericka Pilcher

NPS PHOTO/LOU SIAN

A couple strolls through Cathedral Grove on a quiet morning in winter when visitation is typically low. Signage at the entrance to this area reminds visitors that they are in a quiet zone.

NATIONAL PARKS ARE MANAGED TO PROTECT THE environmental and experiential values of the landscapes they represent. As the nation continues to grow into a more populous, developed, and noisy place, these values have expanded from landscapes to "soundscapes" and include the natural and cultural sounds of national parks. In fact, sounds have been identified by the National Park Service (NPS) as a resource that must be protected. In doing so, the National Park Service is challenged to define "soundscapes," understand the effects of noise on visitors and wildlife, and take appropriate management action when necessary.

Management of environmental and experiential impacts on national parks is increasingly guided by management-by-objectives frameworks such as the NPS Visitor Experience and Resource Protection (VERP) framework (NPS 1997; Manning 2001; Manning 2007). Like other such frameworks, VERP has three principal steps. First, indicators and standards of quality are formulated. Indicators are measurable, manageable variables that help define and quantify desired resource and social conditions. Standards of quality define the minimum acceptable condition of indicator variables. Second, indicators of quality are monitored over time. Third, management actions are taken to help ensure that standards of quality are maintained. With continued monitoring, VERP is an iterative or "adaptive" process, providing feedback that informs management about the degree to which management objectives are attained and the efficacy of management actions taken. This article describes a program of research designed to support application of VERP and management of visitor-caused noise at Muir Woods National Monument (Muir Woods) in California.

Muir Woods National Monument

Muir Woods, a unit of Golden Gate National Recreation Area, lies just north of San Francisco and is a popular visitor attraction, accommodating nearly three-quarters of a million visits in 2007. The park is known for its 560-acre (227 ha) grove of old-growth redwoods. Most visitors experience the park by walking the main trail, which extends about a mile (1.6 km) from the park entrance and follows Redwood Creek.

Human-caused noise has been a management issue in the park for nearly two decades. Initial attention was focused on protection of the threatened northern spotted owl (*Strix occidentalis caurina*) during its breeding season (Monroe et al. 2007). More recently, this has expanded to include consideration of the impacts of human-caused noise on the quality of the visitor experience (Manning et al. 2005; Pilcher et al. 2009). This work has been guided by the VERP framework and supported by a program of research.

Indicators and standards of quality

Initial phases of research at Muir Woods focused on identifying indicators and standards of quality for the visitor experience. The first phase was exploratory, collecting baseline data about visitors and visitor use patterns and probing for issues that generally affect the quality of the visitor experience (Manning et al. 2005). A survey of a representative sample of visitors was conducted in 2003 and a 55% response rate was attained, yielding 406 completed questionnaires. Using a series of open- and close-ended questions, "peacefulness," "quiet," and "the sounds of nature" were found to have a positive influence on the quality of the visitor experience, and "noisy visitors," "loud talking," and related issues were found to substantially detract from the quality of the visitor experience.

Given the apparent importance of soundscape-related issues in the park, the second phase of research was designed to focus more specifically on soundscape-related indicators (Pilcher et al. 2009). Visitors to the park were asked to participate in a "listening exercise" in 2005. This exercise was conducted at three locations in the park (three points along the park's main trail), and visitors were asked to engage in the exercise as they passed each of the three points. A total of 280 visitors participated in the exercise, which consisted of listening to and identifying the sounds heard in the park and rating the extent to which each type of sound was "pleasing" or "annoying." An "importance/performance" analysis of resulting data (fig. 1, next page) suggests potential soundscape-related indicators of quality (Hollenhorst and Gardner 1994; Manning 2007). This analysis suggests that natural sounds such as water flowing in Redwood Creek, birds calling, and wind blowing in the trees are good indicators of quality that contribute to the visitor experience, and visitor-caused noise, such as visitors talking and boisterous behavior, is a good indicator of quality that detracts from the visitor experience. The former sounds are heard by large percentages of visitors and are rated as very pleasing, while the latter sounds are also heard by large percentages of visitors but are rated as very annoying.

The third phase of research was designed to help formulate standards of quality for visitor-caused noise in the park (Newman et al. 2007). Five 30-second audio clips were prepared that included a range of natural and visitor-caused sounds. (Links to the audio sound clips are available from the Park Science Web site at www.nature.nps.gov/ParkScience/index.cfm?ArticleID=346.) All these sounds were recorded in Muir Woods, and the resulting audio clips were created by the National Park Service Natural Sounds Office. These sound clips were ordered by increasing decibel levels, with visitor-caused sounds increasingly masking the park's natural sounds and ranging from 31 to 48 decibels. In other words, the sound clips started with a relatively quiet natural setting with wind, birds, and flowing water, and became increasingly saturated with human sounds in each subsequent sound clip. The audio clips were incorporated into a survey administered to a representative sample of visitors in 2006. A response rate of 53% was attained, yielding 286 completed questionnaires. After listening to each sound clip, respondents were asked to rate the acceptability of the sound on a scale that ranged from -4 ("very unacceptable") to +4 ("very acceptable"). In addition, respondents were asked to indicate which audio clip was most like the soundscape conditions they had experienced in the park.

Respondent acceptability ratings for each of the five audio clips were averaged, and mean ratings were plotted to construct a social norm curve (fig. 2) (Manning 2007). This curve indicates that respondents find greater levels of visitor-caused noise (and

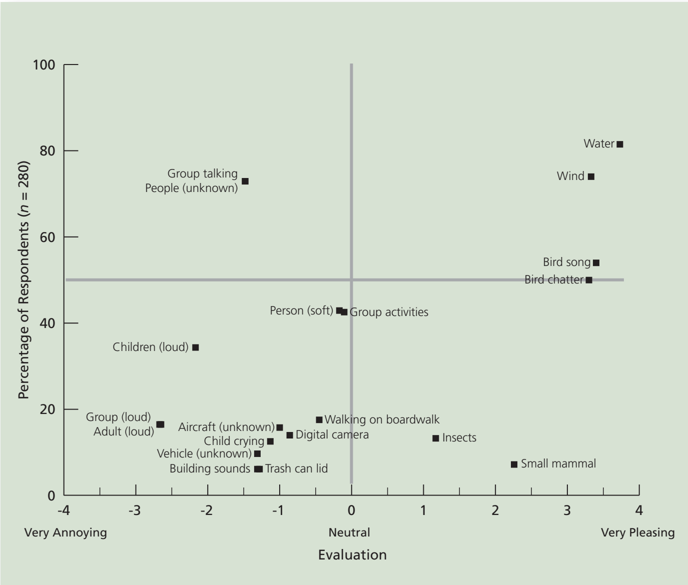

Figure 1. The chart depicts the percentage of study respondents that heard various types of sounds by their mean rating on a scale of very annoying to very pleasing.

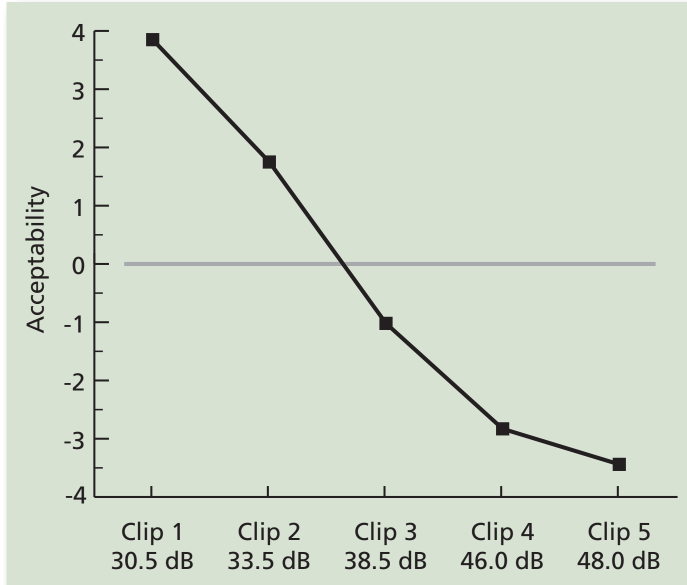

Figure 2. This social norm curve depicts average acceptability of visitor-caused noise on the Cathedral Grove Trail at Muir Woods at various volumes. The sound clips comprise human-caused noise recorded on the trail and played back for survey respondents at varying loudness. Respondents find greater levels of visitor-caused noise (and decreasing levels of natural sounds) to be increasingly unacceptable.

decreasing levels of natural sounds) to be increasingly unacceptable. The point at which aggregate ratings fall out of the acceptable range and into the unacceptable range (i.e., the point at which the social norm curve crosses the neutral point on the acceptability scale) is between audio clips 2 and 3, or 36.7 decibels. Respondents reported the audio clip that best represented the soundscape conditions they experienced in the park on the day they participated in the visitor survey. Most visitors (42.8%) reported that audio clip 2 was most representative, 40.9% reported that audio clip 1 was representative, 12.9% thought audio clip 3 was representative, and 3.4% considered audio clip 4 representative. This means that more than 15% of respondents are hearing visitor-caused noise that is louder than the social norm.

Monitoring

To measure the sound levels in the park, researchers installed a camouflaged acoustic monitoring system approximately 2 yards (1.8 m) off the main trail in Cathedral Grove. This device recorded A-weighted decibel levels (dB[A]) every second. This decibel level is a metric that is an aggregate of sound levels across the range of audible frequencies, weighted to express typical human sensitivities to each frequency band (Fahy 2001). The system used at Muir Woods is certified to measure sound levels accurate to 1 dB(A) and measures sound levels in 31 one-third-octave bands. As noted in the previous section, sound was also monitored by means of a visitor survey that asked respondents which of five sound clips was most representative of the conditions they experienced in the park.

Management

As noted, nearly 15% of visitors to Muir Woods reported hearing more visitor-caused noise than the social acceptability norm as defined in figure 2. Moreover, if visitor use continues to rise, violation of noise-related standards of quality is likely to increase, suggesting that management actions are needed to help ensure that noise-related standards of quality are maintained. But which actions might be effective and acceptable to visitors?

The professional literature on parks and outdoor recreation suggests that a range of management actions can be taken to address the impacts of visitor use (Manning 1999). For example, visitor use levels might be limited or visitor behavior might be altered through educational programs. Generally, educational programs are preferred to visitor use limits because they do not restrict public access to parks and related areas (Peterson and Lime 1979;

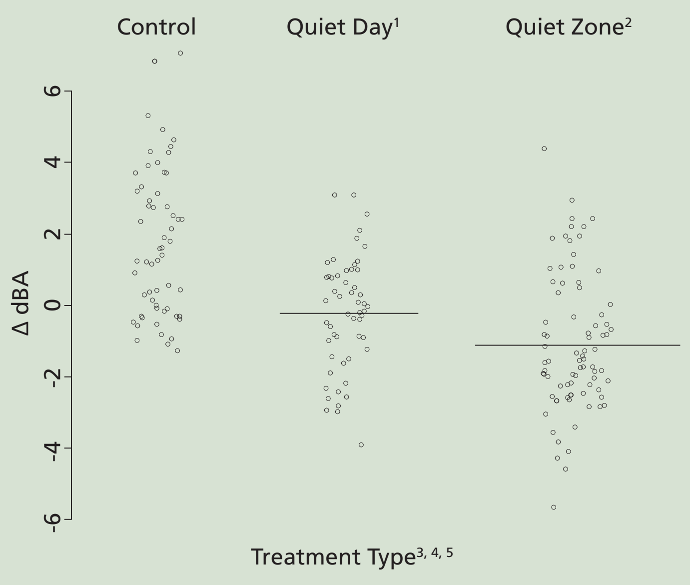

Figure 3. A-weighted decibel (dB[A]) levels during control and treatments.

Notes

[1] The difference between the control and quiet day sound levels is 1.96 dB(A).

[2] The difference between the control and quiet zone sound levels is 2.84 dB(A).

[3] Each circle represents a mean dB(A) level for one hour.

[4] Chart data were measured from 10 a.m. to 6 p.m.

[5] The difference in mean dB(A) among the control and two treatments is significant at the p = 0.01 level.

Table 1. Support for the use of educational programs to reduce visitor-caused noise at Muir Woods

Management action	Percentage*
Quiet Zone	
I strongly support the implementation of a “quiet zone.”	71.6
I support the implementation of a “quiet zone.”	26.4
I oppose the implementation of a “quiet zone.”	1.2
I strongly oppose the implementation of a “quiet zone.”	0.8
Quiet Day	
I strongly support the implementation of a “quiet day.”	72.0
I support the implementation of a “quiet day.”	23.3
I oppose the implementation of a “quiet day.”	4.3
I strongly oppose the implementation of a “quiet day.”	0.4

Note: Data were derived from a survey of visitors to Muir Woods in summer 2007.

*x^2 = 5.19, p = 0.158, and Cramer’s V = 0.101

The point at which aggregate ratings fall out of the acceptable range and into the unacceptable range … is between audio clips 2 and 3, or 36.7 decibels.

McCool and Christensen 1996). However, little research has been conducted to test the effectiveness and acceptability of educational programs to address excessive visitor-caused noise.

A program designed to sensitize visitors to human-caused noise at Muir Woods and to encourage them to reduce the noise they generate was applied experimentally at Cathedral Grove (“Quiet Zone”) and throughout the park (“Quiet Day”) on selected days in 2007. During these “treatments,” signs asking visitors to turn off cell phones, to encourage children to walk quietly, and to talk in a lower voice were strategically placed around the park. Visitor-caused noise was monitored during these periods as well as during a “control” period in which neither treatment was applied. A visitor survey was administered during the treatment and control periods to assess how the educational program affected visitor behavior and how acceptable visitors found it to be.

A-weighted decibel readings were significantly lower on treatment days than on control days (fig. 3). During the Quiet Zone treatment, sound level dropped an average of 2.84 dB(A), which translates into a near doubling of “listening area” (Fahy 2001). This means that visitors during the Quiet Zone treatment had a substantially greater opportunity to hear the natural sounds of Cathedral Grove. The reduction in sound level of 1.96 dB(A) during the Quiet Day treatment was not as dramatic, but was still statistically significant. Findings from the visitor survey indicated strong support for both parts of the educational program (table 1).

Conclusion

Soundscapes are an issue of increasing importance in national parks, and visitor-caused noise is in turn a potentially important component of this issue. At Muir Woods, the visitor experience is enhanced by the sounds of nature—water flowing in Redwood Creek, wind blowing through the old-growth forest, animals calling—but visitor-caused noise can mask these sounds and otherwise detract from the quality of the park experience. Findings from the program of research are being considered as part of the new general management plan that is being developed by Golden Gate National Recreation Area (including Muir Woods), and Muir Woods has implemented a permanent quiet zone at Cathedral Grove (see photo, page 54).

As with other types of visitor-caused impacts in parks, the issue of visitor-caused noise can be analyzed and managed through application of the NPS VERP framework by (1) formulating indicators and standards of quality for visitor-caused noise, (2) monitoring indicator variables, and (3) taking management actions to help ensure that standards of quality are maintained. Moreover, this management approach can be supported by a program of research that provides an important empirical foundation for this work.

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PS

Modeling and mapping hikers' exposure to transportation noise in Rocky Mountain National Park

By Logan Park, Steve Lawson, Ken Kaliski, Peter Newman, and Adam Gibson

NATURAL AND CULTURAL SOUNDS ARE INTEGRAL MEMBERS of the suite of resources and values that the National Park Service (NPS) is charged with preserving, restoring, and interpreting (NPS 2000). Results of research conducted in a variety of national park settings suggest that the quality of visitors' experiences is tied to the naturalness of the area's soundscape (Manning et al. 2006; Tranel 2006; Miller 2002). For example, findings from a recent study in Haleakala National Park in Hawaii suggest that the primary reason for visitors to take an overnight backcountry trip in the park is to experience the sounds of nature (Lawson et al. 2008). Human-caused sounds from aircraft, roads, maintenance activities, and other visitors, however, commonly permeate park soundscapes, making natural sounds and quiet an increasingly scarce resource (Krause 1999).

Recently, the National Park Service has applied indicator-based, adaptive management to address soundscape management and planning (Pilcher et al. 2008). This process involves formulation and long-term monitoring of soundscape indicators and standards of quality. Indicators of quality are measurable, manageable proxies for desired park conditions, and standards of quality are numerical expressions of desired conditions for indicators. As an example, the National Park Service might specify "human-caused noise-free interval duration" as an indicator of quality related to providing visitors opportunities to experience natural sounds and quiet. A standard of quality for this indicator might specify that at least 90% of visitors will experience at least one interval of 15 minutes or more that is free of human-caused noise while visiting the park.

Soundscape-related indicators and standards of quality are now being developed at a number of national parks, but measurement of some indicators, such as highly variable soundscape metrics, is nontrivial (Lawson and Plotkin 2006; Ambrose and Burson 2004). For example, natural sound levels fluctuate because of wind, air characteristics (e.g., density, temperature), and wildlife. Furthermore, visitors' exposure to natural and human-caused sounds is difficult to observe directly or measure through visitors' self-reports in surveys. However, visitor use and noise modeling technologies are potentially useful in this situation (e.g., Lawson and Plotkin 2006; Lawson 2006; Miller 2004; Roof et al. 2002).

The purpose of this article is to demonstrate the use of visitor use and noise modeling tools to provide spatially precise, integrated information about soundscape conditions within a national park setting. In particular, it presents research conducted at Rocky Mountain National Park, Colorado, to model and map visitors' exposure to transportation-related noise while visiting attractions and hiking on trails in the Bear Lake Road corridor. The results of this work are expected to provide the National Park Service with a monitoring tool to track soundscape-related indicators of quality in Rocky Mountain National Park that is adaptable to other national park units.

Methods

Study area

As noted, motor vehicles are one of the most common and widespread sound sources within national parks. Consequently, park soundscapes can be dramatically affected, both positively and negatively, by transportation planning and operations management decisions. The purpose of this project is to use noise and visitor use modeling to quantify and map the effects of shuttle bus service and private vehicle access management in the Bear Lake Road corridor on the park's soundscape. Furthermore, the project combines noise modeling outputs with visitor trip data to estimate the condition of potential soundscape-related indicators of quality.

Data collection

For the purposes of developing the transportation noise model and generating spatially precise estimates of visitors' exposure to noise from Bear Lake Road, four primary types of data were collected in Rocky Mountain National Park during summer 2008: (1) traffic volume by vehicle classification, (2) sound level data, (3) visitor hiking routes, and (4) daily visitation by trailhead. Continuous traffic counters were installed at three locations to measure directional traffic volumes at 15-minute intervals during a two-week period selected to represent the peak period of park visitation (fig. 1, next page).

Sound level data were collected at seven locations over an eight-day period during the park's peak period of visitation (fig. 1). The acoustic monitoring locations were selected to represent a range of soundscape environments within a typical day's hike from trailheads along Bear Lake Road. For example, monitoring sites ranged

Park soundscapes can be dramatically affected, both positively and negatively, by transportation planning and operations management decisions.

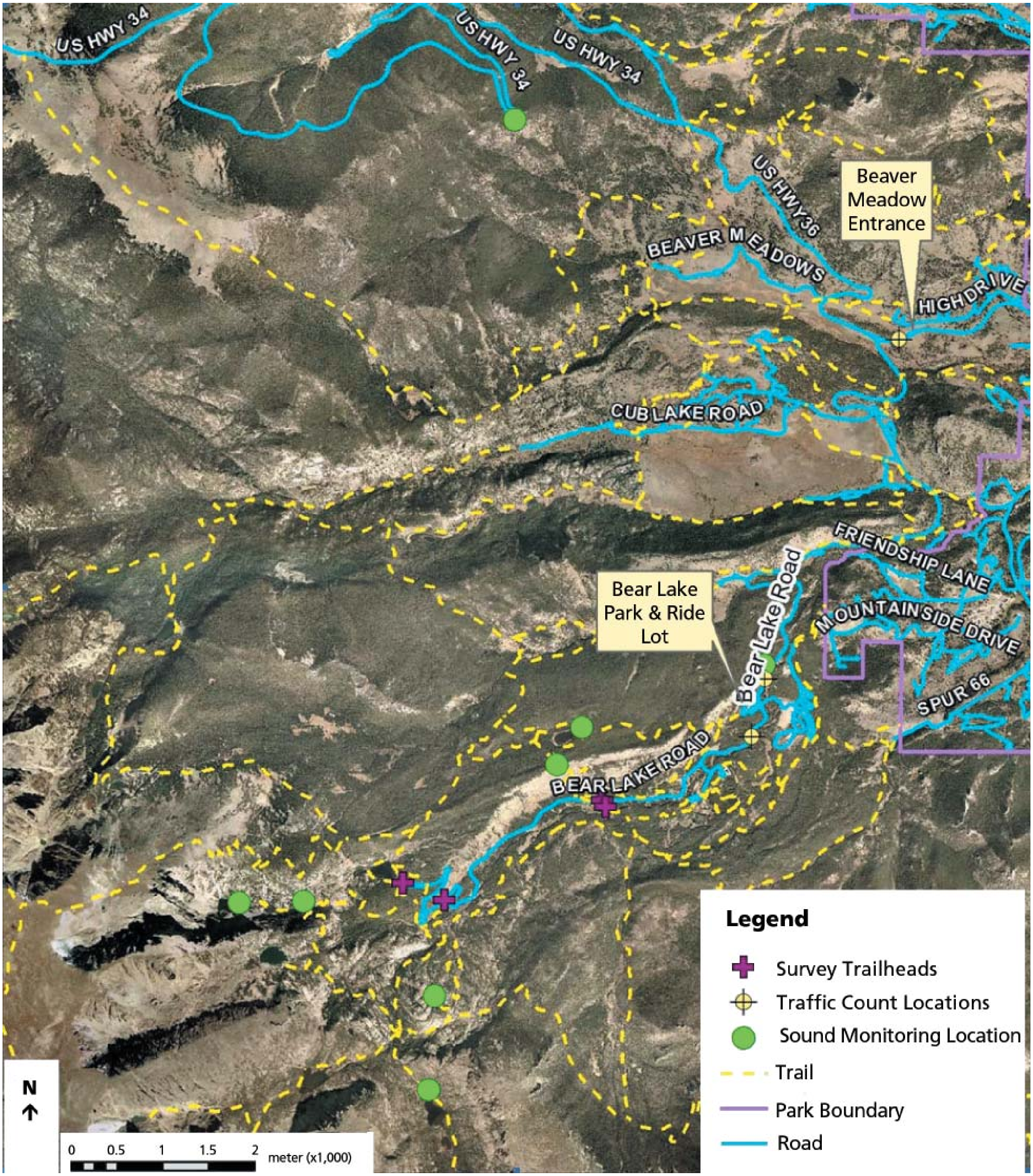

Figure 1. Study area, including traffic volume, sound level, and GPS-based hiking route monitoring locations.

from a roadside pullout at a scenic overlook to an alpine lake 1,800 meters (5,906 ft) from the road. To collect data needed to calibrate the transportation noise model directly to traffic volumes, one of the sound level meters was collocated within approximately 55 meters (60 yd) of the traffic counter installed north of the park-and-ride lot. All eight acoustic monitors were configured to record a sound level measurement at one-second intervals, and four of the monitors were also programmed to record one-third-octave band sound levels. All the sound level meters were calibrated prior to and after sampling using a handheld calibrator.

Visitor hiking routes data were collected on 13 sampling days between 31 July and 14 August 2008 via administration of Global Positioning System (GPS) units to visitors at four trailheads along the Bear Lake Road corridor (i.e., Bear Lake, Bierstadt Lake, Glacier Gorge, and Storm Pass). The GPS units were distributed to randomly selected visitor groups at the start of their hikes and collected at the end of hikes. Daily trailhead visitation was measured with mechanical trail traffic counters, calibrated with data from direct observation (Kiser et al. 2007).

Noise modeling and mapping

Sound propagation modeling of the traffic noise data was conducted using Cadna/A software made by Datakustik GmbH. The geographic scope of the noise model is a 14,000-by-14,000-meter (45,934 by 45,934 feet) square, with its northeast corner just north of the park entrance and east of the eastern park boundary. The model incorporates traffic volumes for the full extent of Bear Lake Road, as recorded by the automatic traffic counters. A digital terrain model was obtained from the U.S. Geological Survey and converted into elevation contours to model the attenuation of roadway sound due to intervening terrain. Propagation algorithms found in the German RLS-90 standard are used within the software to model how vehicle sounds from the Bear Lake Road permeate the surrounding landscape (Kaliski et al. 2007). In particular, the model estimates how sound propagates from the roadway to "receiver locations" specified by the model developer, taking into account intervening terrain, absorption of sound by the ground, energy losses into the atmosphere, and losses due to geometric spreading of the sound wave emanating from the road. In this study, sound pressure level (i.e., decibel) estimates were generated for a grid of 492,000 receivers covering every 20 meters (66 ft) within the study area. The result is a grid of daytime (6:00 a.m. to 6:00 p.m.) average sound levels representing traffic sound conditions during the sampling period. The grid data were then plotted for visual display via a noise contour map to depict the study area's soundscape conditions with respect to noise from Bear Lake Road.

Visitor use and noise exposure modeling

The GPS tracks of visitor hikes were imported into a geographic information system (GIS) environment for error correction and analysis. The data were filtered for positional inaccuracies due to poor satellite constellations and signals interrupted by high mountain peaks. Trip data split across multiple GPS files were assembled into individual trips, and trip attributes, including hiker movement speed, initial trailhead, and intended destination, were joined to the track spatial data.

Spatial statistics tools in the GIS software were used to estimate the amount of time and distance visitors must hike from trailheads to experience alternative soundscape conditions. Estimates were also generated for the proportion of visitors who experience at least 15 minutes of natural sounds and quiet. At the time of the study, the National Park Service had not defined a threshold for road noise beyond which natural sounds and quiet are compromised. Thus, a range of example road noise thresholds were evaluated to estimate the proportion of visitors who experience at least 15 minutes of natural sounds and quiet. The example road noise thresholds used in the analysis include ≤25 dB(A) (nighttime ambient natural sound level measured in the study), ≤30 dB(A) and ≤35 dB(A) (daytime ambient natural sound levels), and ≤65 dB(A) (the level at which noise interferes with conversational tones).

Results

Results of counts conducted to measure daily visitation, by trailhead, suggest that the Bear Lake Trailhead receives the vast majority of visitor use in the study area (table 1). The noise map, developed on the basis of Bear Lake Road baseline traffic conditions, in figure 2 (next page), depicts higher (louder) transportation sound pressure levels in warmer color tones and lower (softer) sound pressure levels in cooler tones. Further, the noise map depicts more heavily visited trail segments with thicker brown lines, and lesser-used trail segments with thinner brown lines. This map suggests that transportation sounds from Bear Lake Road perme-

Table 1. Study area visitation by trailhead, Rocky Mountain National Park

Trailhead	Average daily visitation	Proportion of total visitation
Bear Lake	7,353	89.1
Bierstadt Lake	96	1.2
Glacier Gorge	638	7.7
Storm Pass	170	2.1
Total	8,257	100.0

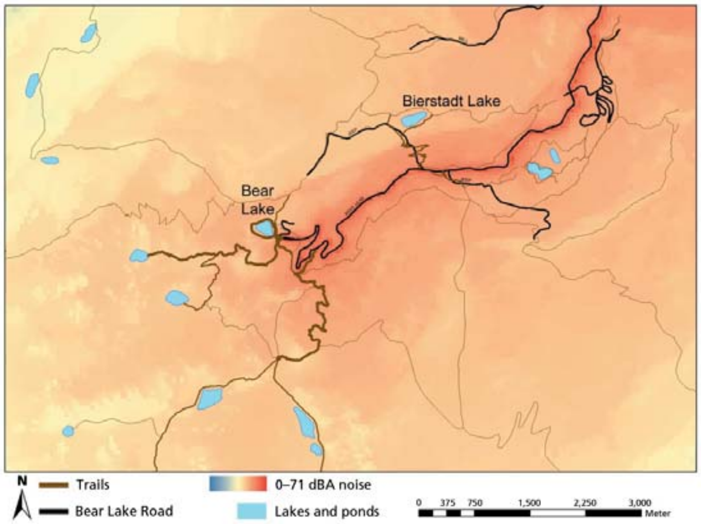

Figure 2. Noise map of baseline traffic volumes on Bear Lake Road and relative intensity of hiking use on adjacent trail network.

ate the park's soundscape throughout the adjacent trail system. The noise is concentrated along the road and falls off sharply with distance. However, the extent of noise in the area requires effort on the part of visitors to reach areas of natural quiet away from Bear Lake Road. For example, model results suggest that visitors following the most direct routes to natural quiet would have to walk more than 1,000 meters (0.6 mile) from all four trailheads in the study area to reach natural quiet as defined by areas of the park with road sound levels that do not exceed 25 dB(A) (table 2). Further, results in table 2 suggest visitors would have to walk more than 1,000 meters (0.6 mi) from two of the four trailheads in the study area to reach areas of the park with road sound levels less than 35 dB(A).

Summaries of the GPS track data indicate that visitors' average hiking speed is 0.55 meter/second (1.2 mph). This hiking speed is somewhat lower than typical average hiking speeds for other areas (van Wagtendonk and Benedict 1980; Bishop and Gimblett 2000), because of many groups' propensity to linger or move more slowly around attraction areas such as Bear Lake and because of the relatively steep topography in the study area. This hiking rate, coupled with the hiking distance results, suggests that visitors would have to hike between 6 and 51 minutes, depending on the trailhead selected, to reach natural quiet defined by areas of the park where road sound levels are ≤30 dB(A), or in some cases would never reach it (table 3). As expected, the estimated travel times to reach natural quiet reported in table 3 vary according to the road noise threshold used to define areas of natural quiet and sounds. Minimum distance to natural quiet varies across the trailheads in the study area by a factor of nearly 10, suggesting opportunities for management to highlight specific trails to visitors that provide greater opportunities for natural sounds and quiet.

Table 2. Hiking distance from trailhead required to reach closest natural quiet*

	Noise threshold / Distance (m)			
Trailhead	25 dB(A)	30 dB(A)	35 dB(A)	65 dB(A)
Bear Lake	1,093	206	155	0
Bierstadt Lake	1,934	1,586	1,542	23
Glacier Gorge	2,097	1,682	1,210	0
Storm Pass	1,907	1,376	973	0

*Natural quiet is defined as sound levels below noise thresholds.

Table 3. Average hiking time from trailhead required to reach closest natural quiet*

	Noise threshold / Travel time (minutes)			
Trailhead	25 dB(A)	30 dB(A)	35 dB(A)	65 dB(A)
Bear Lake	33.1	6.2	4.7	0.0
Bierstadt Lake	58.6	48.1	46.7	0.7
Glacier Gorge	63.5	51.0	36.7	0.0
Storm Pass	57.8	41.7	29.5	0.0

*Natural quiet is defined as sound levels below noise thresholds.

Table 4. Percentage of hiking time visitors experience natural quiet*

	Noise threshold / % of hiking time			
Trailhead	25 dB(A)	30 dB(A)	35 dB(A)	65 dB(A)
Bear Lake	54.5	68.8	77.8	100.0
Bierstadt Lake	12.1	40.1	43.7	100.0
Glacier Gorge	60.2	62.9	74.1	100.0
Storm Pass	0.6	20.1	39.5	100.0
Study area–wide	53.8	63.6	73.2	100.0

*Natural quiet is defined as sound levels below noise thresholds.

The time and distance required to reach natural quiet defined by road sound levels ≤30 dB(A) may present difficulty for less mobile visitors seeking to get away from the transportation noise associated with the road. However, using the 30 dB(A) noise threshold for analysis, the results suggest that, on average, visitors spend a majority (63.7%) of total hiking time in natural quiet (table 4). By contrast, visitors walking from Storm Pass or Bierstadt Lake trailhead will experience elevated levels of noise for most or all of their hike, while visitors starting from Bear Lake trailhead and hiking to more distant lakes (e.g., Emerald Lake or Nymph Lake) will experience almost uninterrupted escape from road sounds. The prevalence of opportunities to experience natural quiet is also sensitive to the manner in which natural quiet is defined. For example, "natural quiet," defined as soundscape conditions in which roadway sound levels do not exceed 65 dB(A), is experienced by virtually all visitors in the study area.

Table 5. Percentage of visitors who experience at least 15 minutes of natural quiet*

Trailhead	Noise threshold / % visitors 25 dB	30 dB	35 dB	65 dB	n	% of total hikers for all trailheads
Bear Lake	26.0	32.5	49.6	83.7	123	89.1
Bierstadt Lake	5.4	48.6	51.4	81.1	37	7.7
Glacier Gorge	45.3	55.7	59.4	85.8	106	1.2
Storm Pass	0.0	33.3	33.3	33.3	3	2.1
Total	24.1	34.1	49.6	82.6	269	100.1

*Natural quiet is defined as sound levels below noise thresholds.

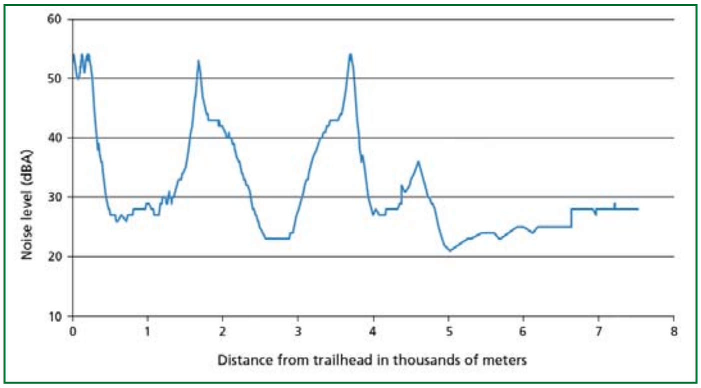

Figure 3. Noise level profile for hiking route from Bierstadt Lake trailhead, to and around Bear Lake.

With respect to assessing whether visitors are able to experience substantive "episodes" of natural quiet, results suggest that about half (49.6%) of visitor groups in the study area are able to do so for at least 15 continuous minutes, using 35 dB as the threshold for traffic noise (table 5). When examined by trailhead, the results provide further insight into visitors' soundscape experience and how it varies across the study area. Hikers near Storm Pass do not usually experience quiet for 15 continuous minutes (33.3% of groups), but almost double that proportion do along the Glacier Gorge Trail (59.4%).

Spatial modeling results also offer insights into how soundscape experiences evolve throughout the course of specific hiking routes. For example, the noise profile depicted in figure 3 is for a hiking route that begins at the Bierstadt Lake trailhead, travels to and around Bear Lake, and then heads into the backcountry. The hiker group embodied in these data experienced abrupt evolutions in their sound environment based on the hikers' route choices, encountering road noise at the trailhead (54 decibels), natural quiet on the way to Bear Lake (26 decibels), then additional road noise near Bear Lake (53 decibels).

Discussion and conclusions

By providing insights on the noise environment, use distribution, and route decisions of visitors in Rocky Mountain National Park, results from this study demonstrate the utility of integrated visitor use and noise modeling to support indicator-based adaptive management and monitoring of park soundscapes. Furthermore, these findings suggest how visitor use and noise modeling can be used to proactively and deliberately assess the effects of transportation planning and operations on park soundscapes. Subsequent analyses with the data and models presented in this article will be conducted to quantify and map the effects of potential modifications to the Bear Lake shuttle service and private vehicle access on soundscape conditions in the study area.

As the results of this work suggest, the modeling tools developed in this study can be used to estimate the conditions of soundscape-related indicators (e.g., percentage of visitors who experience at least 15 consecutive minutes of natural quiet) associated with baseline and alternative management scenarios. However, the National Park Service has not developed specific standards of quality for soundscape indicators in Rocky Mountain National Park. Formulation of empirically based standards of quality for soundscape indicators is recommended to complement the modeling tools developed in this study and to support indicator-based adaptive management of the park's soundscape.

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Aircraft overflights at national parks: Conflict and its potential resolution

By Paul A. Bell, Britton L. Mace, and Jacob A. Benfield

THE TOURIST ATTRACTION KNOWN AS AYERS ROCK, or Uluṟu, in central Australia has undergone remarkable management transformation over the last 25 years. In 1959, experienced bush pilots would bank their single-engine planes tightly around the large rock monolith and turn the aircraft so that passengers had a scenic view of the deep erosion in the red sandstone, just before touching down on the desert landing strip at the base of the massive formation. Thousands of other tourists would follow over the next 25 years, many of them climbing the trail to the top of the monolith and staying in commercial lodging at its base. In 1985 the land was returned to the local Aṉangu people and then leased to the government as a jointly managed park, known today as Uluṟu-Kata Tjuṯa National Park. Out of respect for the spiritual significance of Uluṟu to the Aṉangu people, the airstrip and lodgings at the base of the monolith have been replaced by a modern airport and Yulara Resort outside the park, but the airstrip is still visible in satellite photos even though it is unused and covered with scattered desert flora. Commercial jet aircraft deliver tourists to the new airport, and as they engage in the popular activity of viewing the sunset over the rock formations, noisy helicopters fly other tourists over the terrain. Climbing the formation is still permitted but discouraged, also out of respect for its spiritual significance. In what would come as a surprise to many in park management in other parts of the world, the nearby visitor center at Yulara has a display actually *encouraging* tourists to take a helicopter tour of Uluṟu rather than climb it, again as a sign of respecting its spiritual significance.

This rather unusual circumstance is but one example of the many conflicts park managers encounter when faced with multiple mandates of preserving nature and facilitating visitor enjoyment of parks. These conflicts are especially apparent when it comes to dealing with aircraft overflights, wherein the interests of tourists on the ground (such as backcountry hikers) vs. those in the air, air tour operators vs. whitewater rafting outfitters, and military and commercial entities and safety authorities vs. visitors who want to listen to nature are regularly at odds. Yet, there is hope for at least some degree of resolution to these conflicts.

Commercial aircraft flights are increasingly common. Miller (2008) shows how 3,435 jet departures in one hour in October 2000 essentially overlay the entire United States with their flight paths. Such flights are so common that on 11 September 2001, backcountry hikers knew that something had gone very wrong because there were no sounds from overflights. Diverting commercial flights around national parks raises economic issues for operators and safety issues from altering flight paths. These aircraft are high enough by the time they get over most national

The National Park Service works with the Federal Aviation Administration to develop air tour management plans for units of the National Park System that have commercial air tours. Though no air tour management plans have been implemented yet, a few parks have made progress toward reducing noise and visual intrusions. At Haleakala National Park (Hawaii), for example, air tour operators honor a voluntary agreement to not fly within the crater rim. The photo depicts the historical flight path that no longer occurs here.

parks that they yield less noise than tourist aircraft, but visitors do notice them and they can interfere with some activities (e.g., Williams 2007). Noise may be louder for parks close to a commercial or military airfield.

More common in many parks are overflights from air tours—mostly helicopters or smaller propeller-driven planes that fly low for the view and thus generate louder and more disturbing sounds for those on the ground. These overflights represent a type of conflict derived from multiple-use mandates wherein the enjoyment by one type of visitor comes at the expense of enjoyment by visitors who want a different type of experience. The beauty and expanse of many national parks are particularly spectacular viewed from a tourist aircraft, and for some with disabilities air tours are the only realistic means of accessing the splendid scenery of the backcountry. The popularity of such flights makes them very profitable for operators and contributes to the local economy. A 1996 study of Grand Canyon air tours departing out of Las Vegas, for example, estimated that air tours contributed $504 million to the southern Nevada economy, and that if the tours were eliminated, some $249 million would be lost from tourists who would not visit southern Nevada (Schwer et al. 2000).

The noise from such air tours, however, is considerable. Horonjeff et al. (1993) obtained baseline information about the intensity and duration of aircraft noise in three national parks. Measurements made at 23 separate locations in Grand Canyon National

Park found aircraft sound levels as high as 76 dB(A).[1] By way of comparison, 35 dB(A) is typical of a quiet residential neighborhood at night; the crater at Haleakala National Park is 10 dB(A) in the absence of external sounds; crickets at 5 meters' (16 ft) distance in Zion National Park are 40 dB(A), and a snowcoach at 30 meters (98 ft) in Yellowstone National Park is 80 dB(A) (Ambrose and Burson 2004). (See table 1 to compare the volume of park, urban, and other sounds.) Aircraft noise is audible 79% of the time in some Grand Canyon areas, with as many as 43 separate aircraft noise events occurring within every 20-minute interval. Tour overflights in the Grand Canyon increased from 40,000 in 1987 (Kanamine 1997) to approximately 55,000 in 2005 (Elrod and Joly 2006). On the busiest days, more than 100 helicopters may be in the airspace above the Grand Canyon at any given time. Furthermore, a number of the measured locations in the Grand Canyon produced interesting echo phenomena, where it was possible for a single aircraft to sound as if three or four aircraft were present, even without the aircraft being visible. Aircraft noise can echo up to 16 miles along the inner walls of the canyon (Kanamine 1997). Not a single location recorded in Grand Canyon National Park is totally free of aircraft noise (Mace et al. 2004).

Table 1. National park, urban, and other sounds

Source/Location	Loudness (dB[A])
Crater at Haleakala National Park	10
Whisper (5 m [16 ft])	30
Residential neighborhood at night	35
Crickets in Zion National Park (5 m [16 ft])	40
Conversational speech (5 m [16 ft])	60
Loudest aircraft sound at Grand Canyon National Park (Horonjeff et al. 1993)	76
Snowcoach in Yellowstone National Park (30 m [98 ft])	80
Heavy truck (15 m [49 ft])	90
Auto horn (1 m [3.3 ft])	110
Military jet (100 m [328 ft] above ground)	120
Deck of an aircraft carrier	140

Psychology of noise

Several interesting psychological factors come into play when assessing the impact of aircraft sounds on people. "Noise" is inherently psychological, since a sound must be unwanted to be noise; but what is noise to one park visitor may be music to another. Some people are more sensitive to noise and thus are more annoyed by it. Noise is more disturbing (i.e., has a detrimental impact on performance and enjoyment and is rated as irritating) if it is loud, occurs in bursts at irregular intervals (i.e., is unpredictable), and is perceived as not being under the control of the listener. Moreover, annoyance over the noise is higher if it interferes with tasks (such as listening for natural sounds), if the perpetrator is perceived as unconcerned about the welfare of the listener, and if it is perceived as unnecessary (Bell et al. 2001). All these characteristics contribute to disturbance from air tour overflight noise (Tarrant et al. 1995), and so far we are referring only to impact on humans. For an overview of impact on nonhumans, see Pepper et al. (2003) and several articles in this volume.

Another interesting psychological factor is the attribution people make about the source of aircraft noise; attributing a sound to something that is potentially beneficial might be broadly assumed to make it more pleasing. Mace et al. (1999) had participants rate Grand Canyon scenes while hearing either natural sounds (birds, brooks) or helicopter sounds at either 40 dB(A) or 80 dB(A). Both levels of helicopter sounds negatively impacted ratings of naturalness, preference, scenic beauty, freedom, annoyance, solitude, and tranquillity. Mace et al. (2003) had participants rate national park scenes while exposed to either natural sounds (birds, brooks, wind) or helicopter noise attributed to tourist overflights, backcountry maintenance operations, or the rescue of a backcountry hiker. Regardless of the source, 60 dB(A) helicopter noise resulted in the same lower ratings of the scenes as in the first study. Moreover, helicopter noise attributed to fighting a fire or rescuing an endangered species had similar negative effects (Mace et al. 2000). Results suggest that park management–related overflight noise is just as disturbing as tourist aircraft noise, and that its impact is substantial across demographic variables (Mace et al. 2004).

From a conflict-resolution perspective, overflight noise would be considered a "nuisance" type of conflict, the most common solution for which is segregation (e.g., mandating areas where noise is allowed and where it is not allowed; Deutsch 1973). Such a solution (Special Federal Regulation 50-2, for example) is difficult with overflight noise since it travels great distances. Diverting air tour overflights away from the most popular tourist areas simply results in more complaints from backcountry hikers who are there for solitude. Moreover, the Federal Aviation Administration (FAA) has jurisdiction over the airspace above U.S. national parks, not the National Park Service. Regulation, however, is at least partially successful. The FAA has instituted a limit of 93,971 annual tour overflights in Grand Canyon. The National Park Air

[1] The volume of sounds is often measured in decibels, or dB. Volume or loudness is a psychological experience of the sound pressure, which corresponds to the energy in sound waves as measured in microbars. The human range of audible sound pressures is 0.0002 to 2,000 microbars. The decibel scale, with a range of 0 to 140 dB, is a logarithmic function of microbars such that an increase of 20 decibels represents a tenfold increase in pressure. Thus, a sound of 80 dB is 100 times (102) as intense as a 40 dB sound. Because different frequencies in the sound spectrum have different perceived loudness at the same pressure level, the A, B, and C decibel scales weight the frequencies differently, with the A scale being most common.

Commercial aircraft flights … are so common that on 11 September 2001, backcountry hikers knew that something had gone very wrong because there were no sounds from overflights.

Tour Management Act of 2000 requires the National Park Service and the FAA to produce management plans for each park where air tours occur, and the National Parks Overflights Working Group reports considerable progress in bringing together those representing multiple interests to develop air tour management plans for affected parks (Henry et al. 1999). Nevertheless, the popularity of overflights and the financial benefits that can accompany them will continue to put pressure on the National Park System to allow them, and the demonstrated impacts of overflight noise will continue to bring resistance from affected parties.

Further information

Updates on noise assessment and regulations can be found on the NPS Natural Sounds Program Web site at http://www.nature.nps.gov/naturalsounds/.

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Commentary on the special issue

Managing the natural soundscape: The National Park Service as a learning organization

By Wayne Freimund and N. S. Nicholas

INCREASED PUBLIC ACCESS TO NATIONAL PARKS IS AN important artifact of the last century's technological development. The expansion of aircraft flight-seeing, snowmobile use, and motorcycle touring are examples of technologic advancements that now commonly impact national park soundscapes (see Barber et al., pages 23, 24, and 26, and Park et al., page 59, this volume). To adequately manage these impacts, the National Park Service (NPS) must see them as part of an evolution toward a noisier society rather than as isolated, situation-specific events. The natural soundscape also needs to be perceived across society as an elemental and foundational feature of a protected area. This special issue of *Park Science* illustrates some of the ways the National Park Service is building capacity to maintain the resilience of the natural soundscape (Walker and Salt 2006) in this context. Planning, management, and research are all under way to better understand the roles and functions of natural sound in the ecologic and human values of protected areas. But key questions remain: How do changes in the natural soundscape alter the other components of a protected area to which the soundscape is fundamental? At what point will the broader system change to an entirely different state from which it may never return?

The National Park Service must see [intrusions on natural soundscapes] as part of an evolution toward a noisier society rather than as isolated, situation-specific events.

Intensified demands for soundscape management

This special issue illustrates that complex social and natural systems converge within our national parks. While each park is part of a definable yet dynamic ecological system, it is also embedded in social systems that also are evolving. Within this context the National Park Service has been challenged to expand its management scope to accommodate broadening societal demands. The accommodation of those expectations, primarily for public access, results in the natural soundscape becoming an increasingly threatened resource, nonetheless one that the National Park Service is entrusted to protect.

Peter Senge (2006) suggests that the only way an organization can continue to thrive in a complex environment (characterized by uncertainty and dynamism) is to instill a culture of learning and adaptation into the organization. Donella Meadows (1999) adds that managers should look for leverage points within the system where the greatest desired return can be gained for the effort. By adopting this approach, organizations are more likely to see their connections to (and therefore ability to influence) issues rather than to view them as threats from "outside forces."

Large governmental bureaucracies such as the National Park Service are not often described as nimble and adaptive. Early organizational reactions to "threats" to soundscape resources included legislation, reports to Congress, and development of policies (NPS 2006) and related director's orders (NPS 2000) for planning. For example, the Grand Canyon Enlargement Act of 1975 first explicitly identified "natural quiet as a value or resource to be protected from significant adverse effect" (NPS 1995). However, when the Natural Sounds Program was established in 2000, the National Park Service took an important step in building the organizational learning needed to understand and manage natural soundscapes in the longer term. The Natural Sounds Program "addresses sound-related matters raised by Congress, *NPS Management Policies*, and NPS director's orders. The general mission of the Sounds Program is to "protect, maintain, or restore acoustic environments throughout the National Park System by working in partnership with parks and others to increase scientific understanding and public appreciation of the value of soundscapes" (see Marin and Selleck, page 9, this volume).

Exploring soundscape issues

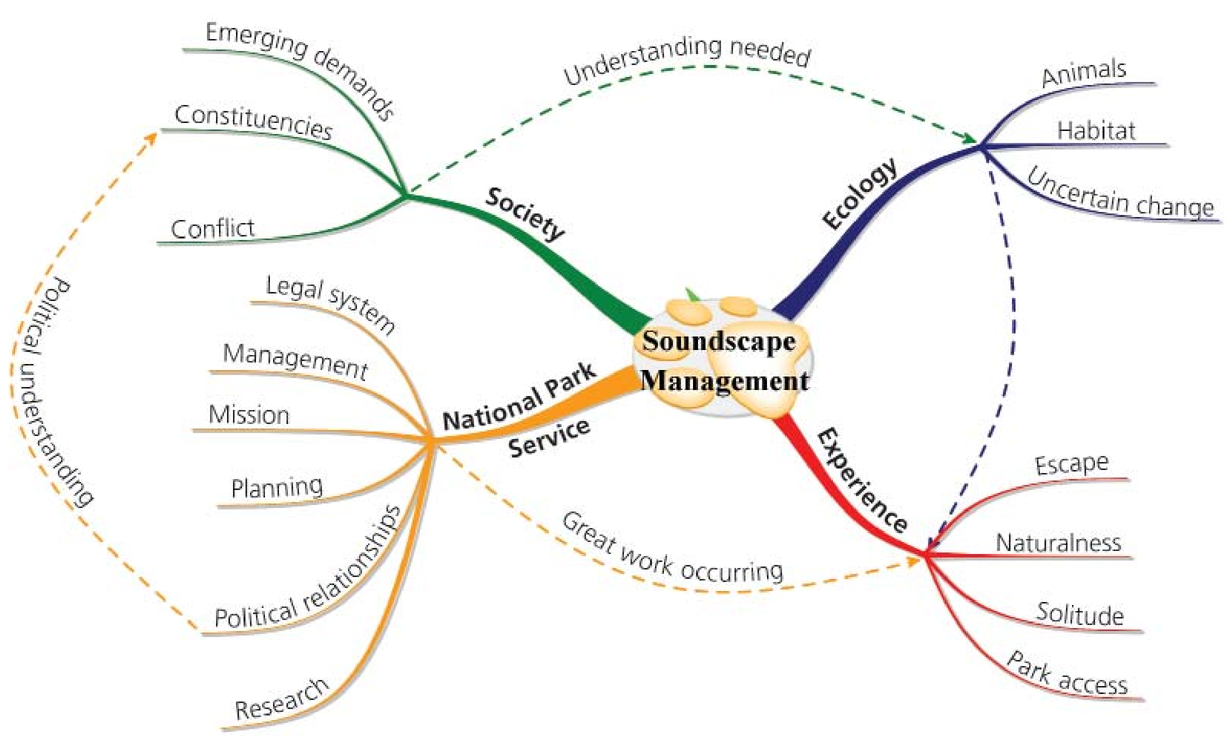
The Natural Sounds Program provides technical acoustic expertise and assistance. It also is building a critical mass of scientists, planners, and managers to grapple with natural soundscape issues within and external to the National Park Service. Within this broad array of expertise is the potential for examining the social and ecological system in which soundscape issues related to national parks persist. While issues often emanate from changes in society, they also must be negotiated through the complex relationships between the National Park Service and society. The traditions and structure of the National Park Service, which are dynamic but slow to change, also need to be negotiated to develop meaningful support to the various actors in the system. Finally, relative to many important issues (e.g., endangered species, air quality, wildfire), there is limited factual information about the relationships of the soundscape to either the ecologic or social values that policy formulation is based on.

The Natural Sounds Program is building a learning system that integrates the relationships among all components of the social-ecological system related to soundscape issues. This special issue documents considerable progress in bringing a wide variety of professionals together to better understand natural soundscape management issues. They have engaged in dialogue and encouraged programmatic learning. We see a merging of technical acoustics research with ecological and social sciences and their application to planning. The Natural Sounds Program serves as the catalyst for numerous forums on soundscape management, including special sessions at conferences, workshops dedicated to developing a research agenda, and numerous informal forms of communication. Considerable learning has occurred through this dialogue and from research and programs for framing future questions, which are emerging (see Manning et al., page 54, this volume).

Becoming a true learning organization

Though the challenges are great, the National Park Service is off to an exciting start with the Natural Sounds Program. This program should expand the ways in which knowledge about functions and values of natural soundscapes are developed, processed, and used. Science, dialogue with visitors and the public, and professional judgment will all be sources for that knowledge. We offer a conceptualization of four primary dimensions for the natural soundscape management that include societal, institutional, ecological, and social/experiential (fig. 1) dimensions. This conceptualization provides one way to consider which kinds of understanding need to be built over time.

Figure 1. The complexity of natural soundscape management is illustrated by the connections among society, the National Park Service, park ecology, and the visitor experience.



The articles in this special issue illustrate that there is more progress in some of these dimensions than others. For example, Park et al. (page 59, this volume) demonstrate an experiential relationship through the limited opportunity for visitors to experience parks without interference from human sounds. Similarly, Barber et al. (page 23, this volume) illustrate cumulative impacts of noise on wildlife. These kinds of studies are valuable and illustrate fundamental relationships between soundscapes and other park values. Continuing with this type of work will reap benefits as we see patterns continue to emerge across varied social and ecological contexts. However, in our opinion, we also need studies of the National Park Service as an institution to see how innovations can be integrated into broader management and other functions as efficiently as possible. The roles and importance of natural soundscapes in society also need to be better understood and articulated, a process that is under way, as this issue of *Park Science* demonstrates.

The conceptualization further illustrates the need to bridge the dimensions of our understanding. For example, while we have studies of ecologic or social impacts related to sound, we have done little empirically to understand these issues in an integrated way. For example, do visitors have a primarily biocentric or anthropocentric orientation to the natural soundscape? How did they develop these perceptions? Does this make a difference in which types of management interventions they may support? Do park visitors reflect a broader population within society? If so, what implications does that have for soundscape or visitor management?

We can also see the need to better understand what mediates the relationships between the National Park Service as an institution and society as a whole. For example, the authors have often heard from park employees and activist group members that the Service lacks the political will to implement the stringent constraints on visitor access that would be necessary to protect natural soundscapes. We need a better scientific understanding of topics like "political will" and "political support" generally. When and how can political will be developed within an agency? How can the demands emerging from society be better anticipated and addressed before they become a political crisis? In essence, how can the National Park Service, or any other land management agency, become more proactive, less reactionary? The literature on natural soundscapes lacks critical contributions by the kinds of political (or other social) scientists who study these kinds of questions.

This special issue represents a good beginning on a long process that will be best served if the complexity of soundscape management continues to be engaged. Purposeful dialogue on soundscape issues among the managers, planners, scientists, and public needs to be encouraged and continued. The National Park Service has the opportunity for true national leadership on this issue and must continue to clarify where the natural soundscape fits into its priorities for protection. It must also continue to build the institutional capacity to execute protection of this resource for the long term.

Each of us tends to see our own crises as in need of the most attention. While we are addressing emerging crises, we also need to look for the patterns and structures within the events to be sure we are dealing with causes rather than symptoms and that we are learning all we can in the process. From that learning, we will ask the kinds of questions that will help us conceptualize our national parks as places where societal relationships are strong and natural soundscapes thrive. That is our collective challenge.

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PS

Field Moment

Crissy Field, Golden Gate National Recreation Area

13 February 2008

ON THE SHORES OF SAN FRANCISCO BAY, Natural Sounds Program acoustic technician Ericka Pilcher performs an on-site listening session at Crissy Field (right). Originally a rich salt marsh, Crissy Field has undergone more land-use changes than any other site in the Presidio of Golden Gate National Recreation Area. From 1921 to 1936, Crissy Army Airfield was the center of West Coast military aviation. When the National Park Service assumed management of the Presidio in 1994, the area was a derelict concrete wasteland. Restoration of the 100-acre (40 ha) area, completed in 2001, re-created dune and tidal marsh habitat. The work linked the marsh to San Francisco Bay for the first time since 1915 when the tidal channels were filled for the Panama-Pacific International Exposition. Together these habitats support 105 different species of shrubs, wildflowers, and marsh plants.

As a popular visitor-use area and restored wetland, Crissy Field serves as an acoustic monitoring site where sounds of the 12th largest city in the United States mingle with nature. Monitoring equipment takes readings of sound pressure level (intensity), recorded in decibels (dB), and frequency, or pitch, recorded in hertz (Hz). Sound equipment allows Natural Sounds Program team members to record sounds from 20 to 20,000 Hz, which approximates the human hearing range. For some types of analysis, the dB levels are A-weighted (dB[A]), to more closely represent the sensitivity of the human ear to different frequency ranges.

NPS/NATURAL SOUNDS PROGRAM (2)

Sound levels in national parks can vary greatly. One of the quietest National Park System units is Haleakala National Park (Hawaii), with sound levels ranging between 0 and 10 dB(A) in the crater. Leaves rustling in Canyonlands National Park (Utah) register 20 dB(A). At 16 feet (5 m) away, crickets at Zion National Park (Utah) register 40 dB(A). Snowcoaches in Yellowstone National Park (Wyoming, Montana, and Idaho) register 80 dB(A) at 98 feet (30 m) away. Thunder at Arches National Park (Utah) reaches 100 dB(A). A military jet flying over Yukon-Charley Rivers National Park (Alaska) registers 120 dB(A). Median sound levels at Crissy Field are around 55 dB(A) during daytime hours (7 a.m.–7 p.m.) and 50 dB(A) during nighttime hours (7 p.m.–7 a.m.).

In addition to collecting sound pressure levels and frequency, Pilcher and the members of the Natural Sounds Program team log individual sound sources using a personal digital assistant with a custom software package, Soundscape V5. Notable sounds at Crissy Field are seabirds, ripples in the water, wind, voices and laughing, dogs, highway noise from a nearby overpass, jets, propeller planes, and helicopters. Data collected at Crissy Field will inform the national recreation area's general management plan and provide baseline sound levels for air-tour management planning.

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